Australian Academy of Science

The year is 2030.

Australia's population exceeds 30 million, with 6.1 million people living in Sydney, 5.9 million in Melbourne and 3.1 million in each of Brisbane and Perth. 18% of the population is over 65; up from 15% in the mid-2010s.

The world's climate has warmed by more than one degree on pre-industrial levels and the social and economic impacts are being felt around the globe. However, the world is responding, and Australian climate scientists are providing significant input into the iterative mitigation and adaptation measures taking place on a domestic and international scale. Thanks to state-of-the-art distributed environmental monitoring infrastructure and climate modelling capabilities, Australians are enjoying the benefits in safety and productivity of ever-more reliable and accurate medium and long-term forecasting of weather and extreme events.

As it has done for 70 years, Australia continues to have primary stewardship of Southern Hemisphere climate science.

Australia's economy continues to be structured primarily around SMEs, but the global shift towards renewable energy generation has spurred a resurgence of investment in Australia's minerals industry based on surging demand for copper, lithium and other non-bulk commodities. Economists are forecasting budget surpluses from the mid-2040s based on a cleaner, greener mining boom mark 2.

There have also been modest advances in Australia's manufacturing and services sectors enabled by the rollout and subsequent improvements in the NBN from the late 2010s as well as widespread adoption of 3D printing technologies and significant developments in nanoscale fabrication, machine learning and automation. Australia remains internationally competitive and has expanded its role in various specialised industries – from medical devices to renewable energy – where local innovation helped to improve the quality and efficiency of the products.

On the strength of these developments, Australia's economy remains strong, but has been surpassed in scale by a number of rapidly developing countries. After dropping out of the G20 in 2020, Australia is now the 29th largest economy in the world.

With unprecedented engagement in international research initiatives, Australia's science and innovation sectors are experiencing a renaissance.

- The investment in quantum computing infrastructure and focus on academia/industry partnerships that started with the National Innovation and Science Agenda in 2015 has positioned Australia as a global leader in the field. Several emerging quantum sensing and communication companies are expanding into international markets from their origins in research and technology hubs in Sydney, Brisbane and Melbourne, and commercial quantum computers are gaining in importance.

- The establishment of the national open research cloud in 2017 combined with changes to research funding rules has placed Australia among the group of global leaders in the wholesale shift to open science. As a result, Australia has a strong role in the international education market.
- The investment in neuroscience capability and infrastructure of the early 2020s has paid dividends with a strong cohort and world-class researchers and two new Australian neurotechnology companies emulating the global success story of Cochlear three decades earlier. A clever combination of advances in local science, instrumentation and information processing keeps Australia companies competitive.
- The hundred-million dollar investment in the UNCOVER earth sciences initiative in 2017 has provided new understanding of the geological history and composition of Australia. This in turn has led to new advanced prospecting technologies that are allowing large-scale exploration and exploitation of the mineral deposits that until now had been hidden beneath 75% of Australia's 'deep-covered' land-mass.
- Australia's nuclear physics community has developed new radio-therapeutics that are achieving significant advances in diagnostics and treatment.
- Australia's lead in polymers and solar energy capture has supported the development of a new, export-focused construction materials industry integrating photovoltaic materials into cladding and roofing, integrating heating, cooling and electricity generation.
- Australia is a respected partner of global science networks that explore the limits of human knowledge. It is part of the space business, through its use of micro-satellites and laser based ground stations to improve the management of the crowded near-Earth space and for the benefit of this widely spread nation.

Critical to achieving these outcomes were the 2016 national research infrastructure roadmap and the 2030 plan for science, research and innovation led by Australia's Chief Scientist, supported by both sides of Government and embraced by business and research. Long-term stable support for research infrastructure has seen the NCRIS of the 2000s evolve into broad underpinning enabling capabilities that support the nimble, agile and globally-connected research system. Bipartisan support for legislated research funding targets and a sovereign infrastructure fund in the early 2020s have now placed Australia among the top 10 OECD nations for public and private R&D investment proportional to population.

In fact, the period from 2016 to 2025 has been described as a decade of rapid transition in public understanding and support for science and innovation in Australia allowing the beginnings of a shift to a knowledge economy for the second half of the Century.

The year is 2016.

The decade of transition is about to begin.

2016 National Research Infrastructure Roadmap
Capability Issues Paper

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Organisation	**Australian Academy of Science**

General comments

The Australian Academy of Science welcomes the opportunity to comment on the *National Research Infrastructure Capability Issues Paper* (July 2016). The Academy strongly supports strategic investment in research infrastructure, in both facilities and skills.

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

In general, the Issues Paper covers the major components of infrastructure that will be required to ensure Australia's capacity to undertake world-class research in areas of national priority over the coming decades.

Areas that the Academy recommends should be given additional consideration are:

1. Big data and e-Research infrastructure, including cross-disciplinary informatics capability
2. Quantum computing infrastructure
3. Nuclear research and engineering infrastructure
4. Climate and ecosystem forecasting capability
5. Material fabrication and characterisation facilities.

The Academy recommends that the roadmap should consider Australia's requirements for these areas in facilities and expertise.

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

The Academy does not have any direct comment on the governance characteristics provided in the Issues Paper. However, the Academy takes the view that infrastructure planning should be based on the best available evidence, including a systematic consideration of the research literature relating to infrastructure establishment, maintenance and governance. There should be a strong focus on identifying capability requirements and building these capabilities. There should be an expectation that Australian infrastructure serves uniquely Australian requirements and operates in uniquely Australian conditions.

Infrastructure facilities should have an independent governance structure and capacity to source expert advice, such as a scientific advisory committee. Each infrastructure facility should be governed according to its own specific requirements.

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?

(Answer to questions 3 and 4.) **Research funding and infrastructure should be planned in a way that allows Australia to participate as a full partner in global research efforts**, for the reasons identified in the Issues Paper. This is particularly true in areas where there is a clear national benefit.

There are some areas where Australian research relies heavily on access to international research infrastructure. For example, access to facilities such as the Hubble Space Telescope, the Integrated Ocean Drilling Program, the European Organization for Nuclear Research, and the European Molecular Biology Laboratory is vital to Australian research. Australian climate research relies heavily on access to satellites and observing networks. Because of this, access to international research infrastructure should be considered to be notionally within the scope of national infrastructure funding.

However, as noted in the Issues Paper, models for supporting access to international infrastructure will vary according to need. For example, in climate research, some access to international infrastructure may operate on a *quid pro quo* basis, with access to Australian facilities being offered – and expected – in return. This approach requires the presence of world-class research infrastructure in Australia – but such infrastructure exists as part of an international network that complements and expands upon the Australian commitment.

The Academy recommends that a general international infrastructure program, mentioned in the Issue Paper, should focus initially on prioritising and facilitating access to international infrastructure rather than directly supporting access – noting that the program may determine that some such support may be required. Access to international facilities should be prioritised where the infrastructure does not and is not going to exist in Australia, where facilities are superior internationally and can be accessed in a cost effective manner, where there are strategic advantages to accessing international infrastructure, or where the infrastructure offers access to equipment or techniques that complement and grow local research capacity.

It is worth noting that access to international infrastructure allows training opportunities that may not be available in Australia – and that there are international facilities run by Australian trained scientists.

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

Yes. The capacity to recruit, train and retain research specialists underlies every research area. The Academy considers that the researcher “pipeline” begins with engagement of students in relevant subjects in primary and secondary schooling, and continues through university *via* training and career planning for all research specialists. Australia should plan to develop research expertise in a way that will increase the productivity of the research workforce and fully exploit physical research infrastructure.

With respect to the skills specific to infrastructure facilities themselves, the ongoing operational and technical support of any infrastructure facility should be considered as part of its ongoing requirements and planned for as part of its governance structures. Maintaining the human resources required for operation is as important as technical maintenance; neglect of human resources will lead to inefficiency and loss of utility. Further, provision of highly skilled staff within infrastructure facilities can significantly leverage the skills and knowledge brought in by users, facilitating more efficient and effective use.

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

Broadly speaking, **national infrastructure facilities present opportunities for specialist research training at doctoral and postdoctoral levels**. Such training should be supported by the institutions using the facilities. Facilities might collaborate with a University to offer Masters and PhD training scholarships. Strategic planning for infrastructure management should include identification of training pathways for both operational specialists and general users.

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

Research training institutions have a responsibility to produce researchers with the skills required to use relevant infrastructure in an individual or team-based capacity, but not necessarily to train technical infrastructure specialists (this responsibility would lie with the infrastructure management in most cases). However, universities can only plan ongoing collaborative training models when support for infrastructure is sufficiently stable to allow longer-term commitments.

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

In general, **Australian research infrastructure should be made available for Australian researchers.**

Access should be optimised to ensure that infrastructure investment is put to the best possible use. Service charges should be kept as low as reasonable, but should be priced to prevent frivolous, poor-quality or other inappropriate use. Where access must be prioritised, scientific merit should be a key determinant of access.

Data and research resulting from the use of national infrastructure should be made freely and publically available as soon as possible.

Where access is granted on a fee-for-use basis, it should be noted that a substantial amount of research funding comes from government sources; it may be possible to streamline funding models in these cases to limit duplication of time, resources and bureaucratic requirements for researcher access.

It is reasonable and expected that Australian research infrastructure be made available for use by Australian industry. The Academy recommends that facilities should have the capacity to charge higher access fees where the results of the use by industry are not to be made public, for example in cases of commercial confidence.

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

Each facility should have an ongoing operational plan, with rolling reviews, and advance notice of any changes in operation (including likelihood of continuing or being shut down). Where possible and appropriate, **the capability provided by the infrastructure should be evolved and developed to meet anticipated needs** in preference to decommissioning. This provides stability and utility to the research community served by the infrastructure. Decommissioning is inherently expensive and disruptive. Research infrastructure represents an enormous long-term investment; that investment should be maximised.

However, **each infrastructure facility should have an end-of-life plan**: a set of criteria by which the facility would be judged to be no longer required, and a set of actions by which the facility will be retired. This plan should be maintained by the facility's governors and updated regularly. The end-of-life plan should be determined on a case-by-case basis, sensitive to factors such as: national research priorities; usage patterns or other demonstrations of national need; availability or development of alternate capabilities; availability of resources. Defunding and decommissioning should happen in a measured, managed and clearly telegraphed manner, to provide security for users, investors and, especially, host institutions.

Succession planning should be part of the end-of-life plan to ensure that whatever need was met by the facility being decommissioned will continue to be met by future infrastructure

It is important that long-term infrastructure facilities be insulated from annual economic variation as much as possible. National research infrastructure should not be defunded abruptly or rapidly; to do so risks serious downstream effects from the disruption of research that uses or anticipates using the facility, often at a disproportionate cost in opportunity and resources.

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

To maximise the usefulness of national infrastructure, **long-term, strategic funding is greatly preferred.** This provides stability and confidence to the research community and promotes integration of infrastructure facilities into long-term research programs.

The Academy recommends a capital investment fund to support new and upgraded research infrastructure. The funding model should be able to support ongoing operating and maintenance costs – including those relating to the skills necessary to operate and maintain the facility. This might be arranged by using a fixed annual proportion of the capital outlays to support ongoing costs. Poor planning with respect to ongoing costs results in inefficient and suboptimal use of infrastructure facilities, disproportionate increases in usage fees, or the prioritisation of commercial interests over academic and public-good research.

The Academy considers the Medical Research Future Fund (MRFF) and the Higher Education Endowment Fund (HEEF) to be relevant financing models.

The Academy also strongly recommends co-funding models with beneficiaries and users of research infrastructure facilities such as state and territory governments, international research collaborations, industry partners, or publically funded research agencies. Leveraging of federal government capital in this way can maximise investment in research infrastructure. Co-funding arrangements should be flexible enough to maximise incentives for co-investment, and should be able to support public good and long-term strategic research endeavours as well as industrial research.

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

Facilities should meet standards and accreditation requirements where required, relevant and beneficial to the research community.

Note that national infrastructure facilities may have a role in setting standards, in order to ensure national interoperability.

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

The Academy does not suggest any particular international models, but strongly recommends that the infrastructure model adopted be based on the best available evidence of cost-effectiveness in achieving outcomes.

The Academy notes that there is a strong existing evidence base both nationally (for example, NCRIS-funded facilities), and internationally (US, UK, European and Canadian facilities). This evidence base should be examined on a systematic basis, and the results of this analysis made public.

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?

In 2007 the High Flux Australian Reactor (HIFAR) at Lucas Heights was decommissioned, replaced with the Open-pool Australian Lightwater Reactor (OPAL). This represents a relatively recent decommissioning of a major research infrastructure facility that provides lessons that can be learned for future decommissioning.

A negative example is the uncertainty over the operational funding under the National Collaborative Research Infrastructure Strategy (NCRIS) for 2015-16. The 2014 budget did not provide for ongoing funding for many NCRIS facilities, with the result that by March 2015 many of these facilities were preparing to go offline or to close permanently, with an enormous negative impact on research projects that depended on these facilities. This approach to defunding led to a significant threat to ongoing, world-class research, and threatened the jobs of up to 1700 NCRIS staff. This experience highlights the Academy's concerns with current funding models for research infrastructure.

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

As stated above, the Academy's preferred model is a capital investment fund to support new and upgraded research infrastructure.

Note regarding the specific capability areas: The Academy submission should be regarded as a general statement of recommendations, and the principles guiding those recommendations. This submission should be read in conjunction with the submissions of the following groups, which have the Academy's support and endorsement:

- AAS National Committee for Astronomy
- AAS National Committee for Cell and Developmental Biology
- AAS National Committee for Data in Science
- AAS National Committee for Earth System Science
- AAS National Committee for Ecology, Evolution and Conservation
- AAS National Committee for Physics
- AAS National Committee for Space and Radio Science
- The UNCOVER Initiative.

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?

The Academy considers information infrastructure to be of paramount importance: high performance computing, high capacity networks, cloud computing, as discussed in the Issues Paper, but also physical libraries, data libraries, repositories, biobanks, models, observation records, and other instances of "scientific memory". The capacity to access, interpret and learn from previous research is absolutely fundamental to ongoing and future research. **Information infrastructure should be designed in a way that facilitates collaboration, creativity and innovative use by researchers in a wide range of disciplines.**

Coordination between existing research infrastructure facilities is also important; synchronisation and coordination of data capabilities reduces duplication, improves integration and facilitates interoperability between facilities, and allows linkages in governance strategies between facilities. The capacity to integrate and cross-references information from different sources and formats is vital for cross-disciplinary research.

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?

The submission from the AAS National Committee for Data in Science identifies a number of specific capabilities that, if developed and applied broadly across national data libraries and repositories, would greatly enhance the national capacity for cross-disciplinary data interrogation and research:

- Metadata services that record sufficient data provenance information to support re-use.
- Metadata and Persistent Unique Identifier or Digital Object Identifier (DOI) services that support the discovery and re-use of individual records or sub-sets of data collections/databases.
- Standards and services for capturing the provenance of research data – including for a range of research data types (observational, monitoring, experimental, derived and simulated data).
- Certification services for data centres or data service providers.
- Linked Data National Infrastructure - services to link data in domain-specific data repositories (e.g., dedicated to diverse disciplines such as life sciences, marine sciences and economics) to facilitate cross-fertilization and solve cross-disciplinary challenges.
- Semantic Interoperability and Ontological services to support cross-disciplinary data integration and reasoning.
- Institutional Repositories to support the "long-tail" of the research community.
- APIs to major data collections (such as Australian Bureau of Statistics data) to enable programmatic access, retrieval and re-use.
- Data Processing Workflows and Workflow services.
- Data Publishing and Citation services.

These capabilities support the principals outlined against Question 30: information systems will be more effective, useful and utilised if designed or adapted to cross- or multi-disciplinary use, broad accessibility and common data structures.

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?

The capability areas *Underpinning research infrastructure* and *Data for research and discoverability* are closely related; these areas should be developed in a coordinated manner.

Other comments

The Australian Academy of Science strongly supports strategic investment in national research infrastructure, including the maintenance of existing facilities. The Academy has long supported the National Collaborative Research Infrastructure Strategy (NCRIS) and welcomes the opportunity to comment on the Chief Scientist's Issues Paper.

The Academy's consultation identified the following existing infrastructure facilities as particularly of note:

- Advanced Instrumentation Technologies Centre
- Atlas of Living Australia
- AuScope Australian Earth Observing System
- Australian Synchrotron
- Australian Urban Research Infrastructure Network (AURIN) spatial portal
- Biodiversity and Climate Change Virtual Laboratory
- Bioplatforms Australia
- MATRIX mathematics training facility
- National Biological Research Collections
- National Computational Infrastructure
- National e-Research Collaboration Tools and Resources
- OPAL reactor
- Stawell Underground Physics Laboratory
- SuperDARN radar network
- The UNCOVER Initiative

The Academy's consultation identified the following capacities for development:

- An Australian Open Research Cloud (computing platform)
- Quantum computing
- Advanced national structural and spectroscopic characterisation facility (incorporating neutron scattering, atomic scale microscopy, atomic scale microanalysis, ultra-high field nuclear magnetic resonance spectroscopy, a free-electron laser, high-end electron microscopy and high quality mass spectrometry)
- Advanced fabrication facilities for materials synthesis and micro- and nano-structures to underpin advanced manufacturing and nanotechnology.
- CRISPR/Cas9 guide RNA libraries
- A high throughput, large scan cell screening facility
- Large scale, high-quality biobanks (expansion of existing capacity)
- A national climate modelling facility with a multi-decade forecasting horizon and a focus on science for Australian arid zones
- Disciplinary and cross-disciplinary informatics/data science capacity
- Virtual national photovoltaic laboratory
- An integrated distributed network of geophysical and remote sensor deployments
- Domestic space-based remote sensing capability