Submission Template

2016 National Research Infrastructure Roadmap Capability Issues Paper

Submission No: ***(to be completed by Departmental staff)***	
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Would you like your submission to remain confidential, i.e. not published on the website?	**NO**

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

The research capability areas in the Issues Paper cover the main strategic priorities for Australia. Some important research areas that could perhaps be more clearly articulated include

- biomedical engineering and bionics
- sustainable agriculture, food production and associated monitoring and remote sensing
- the integration of computation, modelling and data support with experimental capabilities
- renewable energies research, including photovoltaics

In addition, under each of the research themes below, UNSW identifies additional or emerging categories of infrastructure where a national strategic approach would be highly valuable to support the research priorities. Specific examples include:

- a strategic capability in Translational Science and Engineering: It is envisaged that such a capability would support the full invention-to-market pathway, combining advanced design and modelling capability and systems engineering expertise with large scale fabrication and testing infrastructure and linking in to advanced characterisation facilities;
- the need to support not only well-established but also highly developmental instrumentation for characterisation, including imaging.
- a national plan for environmental and remote sensing; and
- inclusion of flagship magnetic resonance techniques to support structural biology, chemistry, metabolomics and materials characterisation.

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

The governance principles are generally appropriate and ongoing support to ensure high standards of governance is essential. No one governance structure should be mandated, but governing boards with expert knowledge and national and international linkages are important. We propose that for some categories of infrastructure, a national coordinating body or advisory council would be highly beneficial, to ensure optimum investment and an integrated, connected approach to delivering access and expertise, including to industry. Because of the extent to which data and expertise may be sourced from public and private sector loci and/or multiple jurisdictions, the aspiration for "whole-of-research" system governance and accountability will often be difficult to realise. For this reason, emphasis should be placed, in any governance structures developed, on communication across, and observation of, international and multi-sectoral developments and openness to challenge. Specific examples, identified in more detail below, where this would result in high added value include (i) geospatial, remote sensing, environmental and marine monitoring, (ii) high performance computing (HPC), simulation and modelling, (iii) data linkage and 'big data' infrastructure.

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

Infrastructure funding should generally aim to focus investments in Australia to build expert capabilities, a skilled workforce and jobs. However, there are important exceptions, as outlined further under the individual research priorities, where an international investment is not only beneficial but actually essential to support Australia's research needs.

Australia already participates in international partnerships that provide access to unique and world-class infrastructure and it will be important to retain and build on these initiatives. Examples are diverse and range from molecular biology (EMBL) through to astronomy and Asian language research.

Where access to other international facilities is supported, this should be funded through competitive grants budgets or in special cases through landmark merit-based access mechanisms.

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

With the increasing globalisation of research, Australia needs to actively participate in international initiatives, which are often ground-breaking and result in unprecedented insights and advances. There are several instances where international research infrastructure projects achieve what would not be feasible for individual nations in terms of financial scale or global observations, either as a single international landmark facility, globally distributed networks or as an international consortium in which Australia needs to be an active participant and co-investor.

Access to international facilities should be prioritised when international research facilities are unique or can deliver a level of infrastructure not feasible in Australia, where there is not yet a critical mass of expert research users in Australia to justify national investment, or where the research itself requires an international strategy. This needs to be managed for expectation and justified by the calibre of the national research contribution.

An obvious example of key international infrastructure is in astronomy, where the fulfilment of the key science objectives of the Australian Astronomy Decadal Plan can only be achieved by Australian co-investment in international capabilities, as outlined further under Question 21.

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

For most complex research infrastructure, highly skilled staff are required to operate and maintain the infrastructure as well as facilitate access and provide expertise and support for researchers who cannot be expected to be proficient in the operation of highly specialised national or landmark instrumentation. Hence, funding of expert support staff enables the equipment to be used more broadly at a national level and facilities can then offer access to researchers from any institution, whether partners in the facility or not.

A major achievement of the original NCRIS funding program was the recognition that without such skilled technical and research support staff, flagship instrumentation would not be utilised to its full potential or by the widest range of stakeholders. This has helped to change the research infrastructure culture in Australia and is internationally recognised as a strength of our national strategy. UNSW strongly endorses the continuation of such funding.

Many NCRIS-funded facilities have built up such specialist workforces, building on the funding provided via NCRIS and the co-investments of State Governments and Universities. Maintaining a highly skilled and specialised staff has been challenging on short-term contracts and in some cases loss of staff has impacted on some facilities. Longer term (e.g. 5-year) funding for specialist staff greatly improves their opportunity to develop a career and prevents unnecessary loss of highly skilled individuals due to job uncertainty after significant investment in them has already been made.

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

NCRIS-funded facilities and national networks contribute to training and skills development both locally and at a national level. Some highly specialised skills and expertise can only be acquired through experience rather than conventional training programs. Support through NCRIS will greatly assist in growing national skill levels. At the same time, expanding and improving specialist capabilities and career paths will attract and retain the specialists who will help drive innovation and new industry opportunities.

NCRIS facilities also provide workshops for industry and public sector staff, provide a mechanism for engaging with industries involved in development of new types of infrastructure and provide educational opportunities for undergraduate and postgraduate students in next generation technologies. In fact, the opportunity for graduates to gain job-ready skills for new industries is a significant benefit of national research infrastructure. For example, the National Imaging Facility (NIF) is collaborating with EuroBioImaging to develop a series of courses in both collaborative infrastructure, and instrument skills development and has been invited to participate in the international workshops of the Global Bioimaging Project, both as instructors and participants. And the Australian Microscopy and Microanalysis Research Facility (AMMRF) is collaborating internationally to plan the next stage of development of its highly successful on-line training platform, mySCOPE.

Coordinated national infrastructure can also play a role in reversing the declining participation of school students undertaking STEM subjects. Outreach around research infrastructure can help to inform the public of the skills a future workforce may require.

The rise of the citizen scientist is likely to see a future where public demand for access to training and skills development may need a different approach. UNSW is already beginning to address opportunities for social engagement as part of the University's 2025 Strategy. A ten-year Roadmap should consider the impact of this changing landscape, including both the need and opportunity for alternative modes of education and skills development.

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

As pointed out above under Question 5, large infrastructure projects often require specialists in various areas of research. In order for Australia's large scale research infrastructure projects to succeed, Australian research institutions must focus on the training of specialists. At the same time, structures must be in place to actively encourage and promote collaborations (both academic and technical) across traditional boundaries. UNSW recognizes this and aims to support the development of technical specialists by various means, for example in the biomedical field, by promoting collaboration between research and clinical departments via Academic Health Science Partnerships, but also involving a diverse range of partners including engineering and physics as well as medicine and biology.

UNSW supports the national radiochemistry training scheme detailed further in the NIF submission to meet the future needs of clinical and research communities. The proposed training scheme will leverage the training, education and accreditation program (TEAP) recently established by the Australasian College of Physical Scientists & Engineers in Medicine (ACPSEM), which provides the educational and accreditation framework for radiochemistry. Currently, there are only a small number of funded radiochemistry registrar training positions, which will not meet future needs. Consideration should be given to additional training positions, funded through National Infrastructure to fill this critical infrastructure gap.

In addition to training of specialists, institutions should also commit to creating career pathways for scientists who are committed to the provision of support for research infrastructure services. In many cases, staff are recruited to these positions from an academic pathway, however, career prospects for non-academics in a public sector research environment are not comparable. This issue is particularly important if the proposed National Health and Medical Research Council changes to funding schemes go ahead. These changes will make it very difficult for enabling scientists like imaging physicists, chemists and informaticians to be funded as primary investigators. As already mentioned above, longer term funding (e.g. 5-year minimum) for research infrastructure operations is also required in order for institutions to be able to recruit and retain staff of the calibre required to operate and facilitate access to national research infrastructure.

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

The criteria for access should be driven by research merit and feasibility. At the same time, infrastructure facilities should be capable of taking on some highly novel and perhaps 'riskier' projects, pushing the boundaries of the available technologies and driving new development.

The prospect of assisting industry to move a product closer to market, evidence of the provision of staff and student training and the likelihood of developing and fostering valuable collaborations are other important criteria.

In many cases, the ability to offer pilot or proof-of-concept studies at no or low cost is an essential part of the access model.

UNSW's own institutional strategy has been to build our major research infrastructure under a supported and shared facility model, open to external researchers, industry and government. We also promote integration of multiple experimental and analytical capabilities, including resources for experimental design, data management and advanced data analysis. Our NCRIS flagship infrastructure is therefore embedded in a strong user-base where it can be used to its fullest potential to solve real problems. All UNSW-hosted NCRIS nodes make their full suite of instrumentation available on these terms, not only the infrastructure directly funded by NCRIS.

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

Planning for any national infrastructure should include lifecycle upgrade or renewal projections and replacement or decommissioning timelines. In many cases, national infrastructure has ongoing value at institutional level and the NCRIS funding model should continue to allow for a variety of end states. Criteria for defunding or decommissioning should take into consideration a variety of metrics, for example data quality, publication or other research outputs, ongoing research demand, maintenance costs and associated downtime, as well as the datedness and technological relevance of the infrastructure and prospects for its repurposing for research or non-research uses.

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

To develop and maintain connected national research infrastructure, it is essential that ongoing support is available from the federal government. This support can then be leveraged through co-investment from stakeholders such as research institutions, state governments, granting bodies and, where appropriate, industry. Infrastructure-related collaboration and co-funding with other institutions requires confidence that the initiative remains important to all stakeholders and that staffing and operational funding will be sustainable. Ongoing investment from the federal government as the "foundation investor" is required to provide the confidence for funding from other stakeholders.

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

Formal ISO or equivalent accreditation is relevant for some capability areas, for example in the biopharmaceutical area where pre-clinical or clinical material or analytical services are provided. This should be decided on a case-by-case basis.

Even where full formal accreditation is not implemented, nationally funded infrastructure should be operated at the highest levels of quality and integrity, from experimental design through to data analysis, reporting and management. This is required across the full research spectrum, irrespective of the final application.

The national capabilities must play a strong role in addressing the well-documented concerns internationally associated with research data reproducibility, data inter-operability and re-use. One of the reasons given for industry not engaging with academia, is the belief that any research used as background IP will need to be repeated. This is a major impediment to innovation at the boundary of industry and the academic sector. This can be largely mitigated by implementing industry standard processes that are ensured through proper documentation and industry accepted accreditation, GLP or ISO9001, and will significantly shorten the time between discovery and innovation. Such implementation will need to be resourced, although by working across national networks, such measures can be put in place in a more efficient and cost-effective manner than if each facility or institution addressed the issues in isolation.

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

The major national infrastructure networks funded under NCRIS, notably AMMRF, the Australian National Fabrication Facility (ANFF) and NIF have developed a world-best model for open access to research infrastructure and undertake collaborative planning for funding and distribution of new high-end flagship capabilities nationally. The EU Horizon 2020 initiatives EuroBioImaging and GlobalBioImaging (http://www.eurobioimaging.eu) are widely acknowledged to be based on the NCRIS networks model and both AMMRF and NIF are actively engaged with these initiatives.

UNSW suggests leveraging the existing expertise and models of collaborative engagement that are being adopted world-wide as well as in Australia, where our major national networks have developed a culture of fostering collaboration and are a model for best practice, with open access policies consistent with the NCRIS goals. At the same time, we need to be adaptable and able to respond rapidly to new technologies and opportunities, as well as having a culture which constantly references research excellence as the key metric of success.

Australia's Integrated Marine Observing System has been one of the global leaders in the marine space, and now works closely with its US counterpart, the Integrated Ocean Observing System (IOOS, https://ioos.noaa.gov/). One lesson to be learned from IOOS is that its funding includes an ocean modelling component, i.e. the model itself is considered research infrastructure, rather than just the equipment used to either run the model (supercomputing) or measure the ocean to validate and calibrate the model. Recognising a national modelling capability (including the researchers required to build it) itself as research infrastructure is important and is a recurring theme elsewhere in this submission.

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?

Further to the response to Question 9, defunding and decommissioning is part of the normal infrastructure lifecycle and should be planned well ahead on a timescale commensurate with the technology. Repurposing of the infrastructure should be adopted where possible and workforce planning should take these prospective changes into account.

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

Co-investment is essential to enable new or upgraded infrastructure to be developed and implemented. State Governments and Universities already provide major co-investment in existing NCRIS capabilities.

UNSW particularly wishes to acknowledge that State Government support in NSW has been invaluable in providing significant investment in our major NCRIS capabilities, for upgrades and new initiatives, enabling them to remain competitive, especially during this transitional funding phase.

Co-investment in major capital equipment is a particular issue, given NCRIS's aim to support next-generation infrastructure. In special cases, the funding rules may need to be sufficiently flexible to allow such investment over multiple financial years or via lease or other non-ownership models.

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?

An overarching consideration for National Research Infrastructure in this field is the need for alignment to strategic directions of the Australian Research Council and the National Health and Medical Research Council. In particular, it has to be ensured that the infrastructure needed for large-scale projects to be funded by the Medical Research Future Fund is not only available but able to be accessed and brought together across organisational boundaries.

'Omics is briefly mentioned in the Issues Paper under Current Capability and Emerging Capability Needs for Health and Medical Sciences. However, it needs to be recognised that modern genomics technology, such as that funded under NCRIS, has completely transformed almost every aspect of life science research. It is now absolutely essential to life sciences, including medical research and diagnostics, as well as for environmental research, and should possibly be considered along with fabrication and characterisation capabilities as underpinning infrastructure. The transformative nature of 'omics technologies is likely to continue and infrastructure investment should focus on enabling expansion and, most critically, integration of multiple 'omics capabilities (e.g. genomics, transcriptomics, epigenomics, proteomics, metabolomics, and most importantly the associated bioinformatics), which would facilitate human population studies, personalised medicine and understanding of microbial infectious disease, the rise of antibiotic resistance and the human microbiome.

Greater integration of 'omics facilities is advocated in the Issues Paper under the Environment and Natural Resource Management capability area, but should be an equally high priority for Health and Medical Sciences.

With respect to **biobanking**, UNSW supports a framework for national infrastructure, in particular biobanking networks with stable national funding, as indicated in the Issues Paper.

UNSW agrees that ongoing support of **biologics** capabilities is critical. The vast majority of biopharmaceuticals are and will be proteins. There should be a retained national (and accessible) suite of infrastructure to support protein-based research, which includes infrastructure for protein production, purification and characterisation as well as structural determination (structural biology). This speaks directly to the national strategic opportunity to expand translational research and industry engagement.

Structural biology itself is undergoing a revolution with the emergence of cryo-electron microscopy tools that can now reveal the hidden machinery of the cell with unprecedented, near atomic resolution. Researchers across Australia will require increasing access to these advanced techniques, which comprise not just an instrument, but a whole ecosystem of specialist expertise matched to instrumentation, to provide an end-to-end solution across the cycle of these complex experiments and their significant data challenges. This ecosystem should be built around the established centres of electron microscopy expertise under an expanded AMMRF network, as proposed in more detail in AMMRF's submission. Particularly exciting is the scientific cross-fertilization of light and electron microscopy that is fuelled by the development of new instruments in both areas. Here, the challenge is to facilitate the transition and integration of new imaging technology into multi-user environments. This will require a willingness and ability to further develop connections among the different specialisations.

At the same time, next generation **nuclear magnetic resonance** (NMR) at ultra-high fields and at high sensitivity in the solid-state means that these NMR capabilities will need to be planned for at a national level. Again there is a specialist NMR network, NNNA, to act as the locus of expertise and management.

There are several new technologies in the area of **biomedical imaging** that should be supported nationally via incorporation into NIF facilities. In particular, UNSW sees a need for next generation ultrasound techniques, magnetic particle imaging and other novel tracers and contrast agents, as well as SPECT imaging, especially pre-clinical SPECT.

UNSW agrees with the need for further development of **radiotracer** capability described in the Issues Paper and would like to refer to and endorse the submission made by NIF, which addresses the issues raised in the Paper in detail.

While 3T **magnetic resonance imaging** (MRI) is perceived as a backbone technology, further development of its capabilities is not only necessary but crucial in order to make the most of a widespread and successful technology. NIF's network of high-end 3T research MRI facilities puts it in an ideal position to offer a network of research-ready, Quality Assurance-attuned systems for multi-site trials and investigations. These 3T sites also contribute internationally to stretching the frontiers of 3T MRI capability with unique expertise in diffusion MRI (the Florey), spectroscopy and magnetic resonance elastography (UNSW), translation of ultra-high field capabilities (University of Queensland and the Florey), cognitive neuroscience (Swinburne) and large animal model translation (LARIF).

A national collaborative network of open access facilities spanning fundamental research and pre-clinical capabilities, linking through to clinical settings is now well-established. Imaging plays a strong role in the translation pathway as well as reverse translation, i.e., informing future molecular and pre-clinical research using data from human and animal imaging. Translational research has a wide range of meanings, but UNSW would particularly like to emphasise the importance of having **integrated preclinical and human imaging capabilities** and expertise as already developed under NCRIS. In addition, high end imaging capabilities, which are currently available at University facilities, must also be made accessible in clinical environments to facilitate answering real clinical research questions and develop relevant applications.

Regarding **big data** capabilities for health research, current infrastructure suffers from key deficiencies, which include duplication, fragmentation, lack of interoperability and inefficient processes and governance. UNSW recommends a redesign to create (i) a framework for the longitudinal data that need to be integrated to build a national health big data resource that will unlock major research opportunities for Australia; and (ii) a set of design principles and a governance structure to support this essential capability.

Also in the area of health data, infrastructure to support **pragmatic clinical trials** (PCTs) is an emerging need. Infrastructure to support PCTs includes mechanisms to engage with communities and stakeholders, systems for patient recruitment and randomisation, standardised tools for data generation, capture, analysis and management, including infrastructure to catalogue interventions and their implementation.

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

Australia's associate membership of European Molecular Biology (EMBL) is currently funded under NCRIS. This has enabled the development of the EMBL Australia network which is providing a career path for emerging scientific leaders, new infrastructure particularly in bioinformatics and systems biology, and new imaging technology in light and electron microscopy. Ongoing engagement in EMBL is strongly supported by UNSW. The opportunity to link and integrate new optical imaging techniques into the multi-user facility environment is particularly exciting.

As part of this strategy, UNSW also recommends ongoing involvement in Global BioImaging (http://www.eurobioimaging.eu/content-page/global-bioimaging-project), an international network of collaborating infrastructures in biological and biomedical imaging for life scientists supported by the EU Horizon 2020 program. AMMRF and NIF are founding partners in this initiative. Other international projects, in which Australia is currently engaged, include Enhancing Neuro Imaging Genetics Through Meta Analysis (ENIGMA, http://enigma.ini.usc.edu/), the Dominantly Inherited Alzheimer's Network (DIAN, http://www.dian-info.org/) and the Alzheimer's Disease Neuroimaging Initiative (ADNI, http://adni.loni.usc.edu/). The Human Connectome Project in the US (http://www.humanconnectomeproject.org/) and the Human Brain Project in Europe (www.humanbrainproject.eu) should also be considered.

International Landmark infrastructure of importance to health and medical sciences will continue to emerge. Some (for example free electron lasers) will be at a scale that Australia will not be able to fund at a national level, at least initially. In order for Australian research to stay internationally competitive, the national infrastructure framework should retain sufficient flexibility and agility to enable strategic engagement in international landmark facilities, where this can be shown to be of high added value to medical and health sciences research priorities. A specific example, under the auspices of the National Imaging Facility would be to join the international PET Explorer consortium in the development of transformative low-dose, whole-body PET imaging.

Access to internationally available infrastructure is not practical for cutting edge clinical studies that require human imaging, although involvement in international multi-site studies can be enabled and facilitated in special cases. UNSW recommends building on the NIF program to make world-class imaging facilities more available for clinical research. This will have the added advantage of attracting and retaining imaging specialists who currently go overseas to engage in high end research elsewhere.

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?

Biomedical engineering and bionics will continue to be a strength in Australia, for fundamental research, biomedical applications and as the basis for new industries. Full realization of the commercial potential in this area will require a Translational Science and Engineering capability as detailed in response to Question 1, including fabrication, advanced imaging, microscopy and high-resolution analytical capabilities, as well as translational neuroscience platforms enabling multimodal electrophysiology, gene expression targeting and transgenic animal model development.

A further opportunity will arise for coordinated imaging and therapy programs of research at the national level should Australia proceed with the establishment of a proton and heavy ion cancer therapy facility (proposals are under development for several potential Australian sites). This is a natural area for collaboration between NIF and the radiation physics/oncology communities.

Overall, the infrastructure supporting this sector needs to continue to challenge itself to be adaptable and flexible to meet research needs, including working across administrative boundaries to meet the needs of major research programs.

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?*

Tools for **high precision isotopic analysis** of minerals have evolved enormously in recent years and are essential to understanding the mineralization processes that underlie Australia's resources industry. As an example, our geologists require access to new-generation secondary ion mass spectroscopy (SIMS) to remain at the top of their field. The AMMRF has a rolling 5-year plan that currently includes provision for world-class open-access national microanalysis facilities.

The need for **groundwater research infrastructure** is argued convincingly throughout the Issues Paper. Given its importance to agricultural production and water security for rural communities, mining and manufacturing, the national strategy for groundwater should be strengthened further. UNSW strongly supports the expansion of the network of sites managed under the NCRIS Groundwater capability to cover a larger range of economically and environmentally relevant regions. UNSW also endorses the proposed ANSTO Environmental Tracers initiative, which would ideally coordinate with groundwater and related monitoring programs.

Freshwater ecosystems monitoring is currently not well supported by the national infrastructure, although these represent serious degradation and sustainability challenges nationally. The need for a long-term strategy for freshwater ecosystems should be included as part of a coherent national strategy for environmental and ecological monitoring.

As noted in the Issues Paper, there is an imperative for cross-disciplinary approaches and integrated data. To address this with regard to **environmental monitoring**, UNSW recommends that field infrastructure dedicated to monitoring environmental parameters should be planned coherently and considered for co-location where feasible, to allow for integration and data linkage. This could be facilitated by an inter-facility working group. An overarching strategy to link and integrate monitoring data should be part of the planning.

UNSW agrees that the **marine environment** is a continuing high priority, and in particular endorses the National Marine Science Plan. As outlined in the Plan, the expansion of Integrated Marine Observing System infrastructure, especially with regard to inclusion of coastal regions, is considered essential.

UNSW appreciates that the **Australian Community Climate and Earth System Simulator** (ACCESS) model is listed as existing research infrastructure, which will continue to require attention. Considering that an estimated5% of GDP (~$65 Billion annually) are sensitive to climate variations[1], even a modest improvement in our ability to understand and predict climate variations is worth billions to the economy. To do this requires weather and climate modelling systems, such as ACCESS, a nationally shared infrastructure for weather and climate research and prediction. Continued support for facilities like NCI and the Pawsey Centre, along with data storage systems reaching toward the Exabyte range, is essential to run model simulations and store and disseminate data. However, what has been lacking so far is a software infrastructure capability in the form of software engineers to enable climate scientists to optimise the use of HPC and high performance data (HPD) infrastructure. UNSW strongly recommends building a specialist software capability around HPC and HPD infrastructure.

Notably, the need for suitably skilled support staff to act as an interface between researchers and NCI/ Pawsey HPC/ HPD infrastructure is also an issue for other fields, for example materials science, as pointed out under Question 23. Provision of the right mix of support staff to connect institutional researchers to national infrastructure is now well-recognised and should be integral to future funding programs. Building this expertise in Australia will also build capacity and expertise in a workforce which can contribute much more broadly to the economy.

Under Question 21 below, UNSW proposes that Australia has the opportunity to play an international role in **hyperspectral remote sensing** (HRS) infrastructure, which would contribute valuable data for environmental research, including marine and fresh water quality, coastal and offshore monitoring, terrestrial ecology, agriculture and forestry data collection.

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[1] CSIRO (2014) Next Generation Australian Community Climate and Earth-System Simulator (NG-ACCESS) – A Roadmap 2014-2019 by Tom Keenan, Kamal Puri, Tony Hirst, Tim Pugh, Ben Evans, Martin Dix, Andy Pitman, Peter Craig, Rachel Law, Oscar Alves, Gary Dietachmayer, Peter Steinle and Helen Cleugh. CAWCR technical report CTR 075.

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

There is a very strong case for Australia to participate in international collaboration in the marine and atmospheric disciplines. Examples are the continued integration of the Integrated Marine Observing System into the Global Ocean Observing System (GOOS, http://www.ioc-goos.org) as well as the new Tropical Pacific Observing System (http://tpos2020.org).

UNSW also recommends that international engagement should not only focus on Australia engaging with larger, well-established international collaborators. We have responsibilities in our region to engage with and fund or co-fund infrastructure collaborations with developing nations who can be valuable partners in monitoring climate, environment and natural resources, as well as developing their own infrastructure and expertise. UNSW's 10-year 2025 Strategy identifies the need for our research to add value to society, to address the grand challenges of our time including climate change, and to do this by partnering locally and internationally, including with our neighbours in the Asia-Pacific region.

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?

UNSW would like to see an emphasis on enhancing the value of environmental data by linking the data to centres for advanced data science and visualisation infrastructure. The development of visualisation tools that make environmental research data available both to researchers themselves, to end-use stakeholders and to the broader community, is increasingly important.

Presently much of the NCRIS monitoring data is typically acquired and provided in delayed mode and archived primarily for research purposes, but the uses and impact of the data would be significantly enhanced if data could be shown in real time. In addition, environmental sciences capabilities should be resourced to work with data visualisation scientists to conceive of new ways to interrogate and analyse multidimensional data collections.

UNSW also encourages the cross-disciplinary use of infrastructure outside its traditional applications. For example, whilst the medical importance of magnetic resonance imaging (MRI) has long been understood, the application of MRI to industry and agriculture is almost untapped. Working in concert with agricultural and industrial researchers, the infrastructure and expertise in NIF has enormous potential to drive and increase the competitiveness of Australian industry (e.g. imaging of process and electrochemistry) and agriculture (e.g. root imaging to better understand plant growth in various soils, salt transport in engineered phenotypes and plant phenomics need more focussed attention).

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?

The development of the NCRIS-supported ANFF and AMMRF networks of advanced fabrication and characterisation infrastructure has been a key factor in development of Australia's international leadership in **quantum technologies**. There is now a very real opportunity for Australia to establish new high-tech industries on the basis of this research leadership and the concentration of highly skilled graduates it has yielded. However, upwardly compatible pre-pilot production lines are required in order to maximise engagement between the public and private sectors and guide the transfer of research outcomes to market-ready products. This process would be well served by the Translational Science and Engineering capability proposed in the response to Question 1.

UNSW supports a plan by the AMMRF, which is further detailed in the AMMRF submission, to host a national **atomic-scale microscopy** capability consisting of a grid of strategically-located high-end open-access facilities embedded in a network of mid-range instruments. With recent breakthroughs in aberration correction technology, atomic-scale microscopy is increasingly essential for materials, nanotechnology and chemical research, impacting on industries such as electronics, chemical processing, manufacturing and mining, and future industries that will emerge in quantum computing.

Nuclear magnetic resonance (NMR) is a critical characterisation capability for chemistry, biology and materials sciences, as well as health and medical sciences. A national collaborative network of NMR research facilities, the National NMR Network Australia (NNNA), is coordinated through UNSW and has recently been expanded to cover 17 institutions Australia-wide. World-leading NMR instrumentation in two main categories is much too expensive to be funded at institutional level: (i) next generation ultra-high field (GHz) NMR for protein structure and function and (ii) high-resolution/high-sensitivity solid-state techniques involving dynamic nuclear polarisation. Such flagship capabilities need to be embedded in a strong facility network providing specialist support staff and expertise to prospective research users. If Australia does not invest in next-generation flagship NMR, we risk becoming uncompetitive in large areas of chemistry, materials science, biology and medical sciences research.

The Issues Paper correctly identifies the key emerging capability needs for **astronomy**, including the Giant Magellan Telescope (GMT), the Square Kilometre Array (SKA) and the underpinning HPC infrastructure which are further detailed in the submission by the Australian Astronomy community and the Australian Astronomy Decadal Plan for 2016-2025. UNSW agrees with the view expressed therein that Australia's ability to play a leading role in these major global infrastructure projects is built on human capacity and our international reputation in key areas of astronomical science and instrumentation.

"An Australian Strategic Plan for Earth Observations from Space" (Australian Academy of Science and AATSE, 2009) describes Australia's needs for Earth Observations from Space (EOS) remote sensing data to meet urgent national challenges in climate change, water, natural disaster mitigation, transport, energy, agriculture, forestry, ecosystems, coasts, oceans and national security. The need for Australia-specific remote sensing has further increased since then, and coordination of key stakeholders nationally is at an advanced stage. **Hyperspectral remote sensing** (HRS), in which the surface of the Earth is imaged at high resolution in many simultaneous wavelength bands, is able to help meet many of the identified EOS needs and is well proven on airborne platforms, with CSIRO and DST Group possessing world-class expertise.

A staged approach to the development and operation of an affordable HRS satellite capability based on a small number of nanosats (for 30m ground resolution) and proceeding to a small number of microsats (for 5m ground resolution) is feasible today. The global space sector is currently undergoing rapid transformation and it is now feasible to develop and operate sophisticated space-based technologies and spacecraft to help meet national needs.

Growth in areas such as commissioned **payloads** and development of space-borne **remote sensing** capabilities will be supported by access to advanced fabrication facilities, such as those currently offered via ANFF. UNSW endorses infrastructure and skilled engineering support staff who promote innovation by enabling the integration of elements drawn from different research disciplines.

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

UNSW agrees with the view expressed in the Issues Paper that international collaborations are essential for enabling astronomy and space science capabilities due to the nature and scale of the infrastructure and specialist personnel involved.

Similarly, access to international facilities is critical in other areas where facilities or specialised instruments for specific measurements are not available within Australia. For example, free electron lasers, spallation neutron sources and total neutron scattering measurements are not available at the Australian Synchrotron and the OPAL reactor. Access to international facilities serves two functions, firstly allowing Australian researchers to perform experiments and gain insights not possible here, whilst also providing experience in techniques that might be installed at our National Facilities at a later date.

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?

UNSW recommends a stronger focus on supporting infrastructure related to certain areas of engineering within the Advanced Physics, Chemistry, Mathematics and Materials capability area. Some of these could be co-funded by industry.

- An enhanced focus on the translation of research outcomes through to pre-commercial prototyping. This requires investment in advanced design and modelling tools and higher throughput fabrication, testing and analytical facilities as well as systems engineers to guide the product development process.
- The transport sector is poised for dramatic disruption via the convergence of automation and communication technologies with substantial impacts in terms of safety, employment, car-ownership, land usage and livability. Driverless vehicle adoption in Australia will make

substantial improvements on the $27 Billion cost of road trauma per year and the $20 Billion economic cost of road congestion per year. An integrated national facility to bring together the many groups developing infrastructure in this field is needed.

- The national electricity market is valued at $11 Billion per annum. Predicted investment in the next 10-20 years will be as high as $100 Billion total in Australia as we transition to a more distributed/ decentralised network. UNSW recommends research infrastructure for electrical power networks research for both academic and industry-based research. This would include infrastructure to support fundamental research into various emerging technologies, such as smart grid communications and control, flexible AC transmission equipment, asset management techniques, energy storage and high-voltage DC systems. A successful overseas example in this is area is the University of Strathclyde's Power Networks Demonstration Centre (http://pndc.co.uk/).
- Total construction works in Australia exceed $200 Billion annually, contributing to about 14% of its gross domestic product[2] and contribute 17.4% of workforce employment[3]. To support innovation in many fields of engineering (civil, structural, mechanical, manufacturing, mining, petroleum, materials and electrical), a centralised national testing facility is needed to enable development and testing of full-scale infrastructure systems involving new technologies under real, complex, short- and long-term loading conditions. The facility would result in partnerships between companies, universities and government authorities, increasing Australia's productivity and international competiveness.
- Renewable energies and particularly photovoltaics are an important field in which Australia retains a global leadership position. The research infrastructure needs of the PV community have been laid out by the Australian Centre for Advanced Photovoltaics (ACAP, led by UNSW) and the list is dominated by the extremely valuable capabilities already provided by NCRIS via AMMRF, ANFF, the Synchrotron and ANSTO. To take the research to the next level, the creation of "incubator" facilities would support emerging young innovators who will develop the new industries based around renewable energies.

The field of material sciences faces a lack of software engineering capability similar to that described under Question 18: it is lacking in highly qualified support staff with domain area expertise to act as an interface between material science researchers and HPC infrastructure to enable high performance computational modelling. A capability for *in silico* materials characterisation would significantly amplify the benefits of infrastructure investments into state of the art materials nanofabrication (ANFF) and characterization (AMMRF and NIF) as well as computing. Materials modelling will be a transformative enabling capacity over the coming decade. The increasingly pivotal role of materials simulations in the design of functional materials has been recognised locally at UNSW with the constitution of the Integrated Materials Design Centre (http://www.imdc.unsw.edu.au) as well as overseas in the US (http://www.whitehouse.gov/mgi) and Europe (http://actu.epfl.ch/news/epfl-has-become-the-swiss-capital-for-research-on-/).

[2] Australian Bureau of Statistics, Construction Work Done, Australia, http://www.abs.gov.au/ausstats/abs@.nsf/mf/8755.0: accessed 28 January 2016.

[3] http://www.abs.gov.au/AUSSTATS/abs@.nsf/mf/8155.0 including manufacturing and mining sectors.

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?

The Understanding Cultures and Communities capability should be underpinned through national research infrastructure which supports the enablement of Smart Cities and Connected Communities. Such investment should align with the Commonwealth Government's Smart Cities Plan (2016) and look at connecting communities to open data, analytics visualisation tools and emerging distributed infrastructures, such as those required to support the internet of things. Investment should aim to provide open data and open software platforms to connect communities, researchers, government and business. More competitive national Smart City data and technology infrastructure will support the growth of the knowledge economy and new international and local business opportunities, similar to what has been enabled through the Singapore Smart Nation initiative (http://www.smartnation.sg/).

UNSW strongly supports enhancement of existing investments in Trove, the Australian Data Archive and the Australian Institute of Aboriginal and Torres Strait Islander Studies (AIATSIS). It is important that such research infrastructure is developed and supported by standards from national services for curation of data, publications and cultural material.

UNSW also strongly encourages an enhanced investment in Asian language research resources in the National Library of Australia's collection in keeping with the rapid expansion of comprehensive digital resources and archives that is occurring in Asia.

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

Australian social science research capabilities could be strengthened by support for links between Australian universities and curatorial organisations including the Australian Data Archive, and international research infrastructure such as Data Documentation Initiative (http://www.ddialliance.org/) and Interuniversity Consortium for Political and Social Research (ICPSR, www.icpsr.umich.edu/icpsrweb/). These organisations draw on international expertise of researchers, and data and IT specialists, to deliver tools, standards, protocols and training for existing and emerging research practice and technologies. The international perspective is an essential starting point in planning the future resourcing of this type of research infrastructure.

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?

In relation to all e-Infrastructure, implementation plans should be developed for all NCRIS-funded portals and other software builds, where they do not already exist. For example, the Australian Urban Research Infrastructure Network (AURIN) portal should be released comprehensively as a complete open source project. This would be a significant contribution to the urban research community in Australia, and also a valuable international contribution which could be realized through working with bodies including: Research Data Alliance, the OSGeo Foundation and the OpenCity Smart Geo4All initiative.

Greater attention should be given to issues of data storage, preservation, education and access surrounding Australia's world heritage sites, cultural heritage and languages. Consideration might be given to whether a national/ regional counterpart to the European Research Infrastructure on Heritage Science (E-RIHS, http://www.e-rihs.eu/) is necessary or desirable.

One element of materials conservation, the digitisation of important museum and archaeological artefacts, is an increasing area of importance. This comprises 3D imaging (micro-CT and 3D electron microscopy), immersive visualisation, and 3D replica production via high-resolution 3D printing. These activities are supported by a suite of NCRIS imaging and fabrication facilities.

National Security

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

In agreement with the Issues Paper, UNSW supports the development of capabilities related to water security, as already outlined above under Question 18.

As already mentioned above under Question 21, Australia is currently dependent on foreign satellite providers for Earth Observations from Space (EOS) remote sensing data, resulting in an inability to significantly influence international EOS capabilities to meet Australia-specific needs. Development of national remote sensing capabilities would be highly relevant to National Security, biosecurity and water security.

Australia's world-class research in areas such as advanced electronics and sensor technologies is under-represented in defence hardware applications due to the lack of local fabrication facilities capable of pilot-scale semiconductor device manufacturing. Access to international foundry facilities for defence-related projects is hampered by ITAR restrictions. The establishment of a semiconductor device foundry in Australia would provide unprecedented opportunities for high level defence projects to be completed locally as well as providing a pathway for commercialisation of research outputs in fields such as quantum technologies and medical devices.

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

Quantum technologies to support national security also include quantum communications. The international quantum community sees as part of its long term roadmap the development of global ultra-secure communications networks supported by quantum encryption and quantum key distribution. Secure global communications will include ground-to-satellite, satellite-to-satellite and satellite-to-ground quantum communications. Quantum ground stations (derived from optical tracking telescopes) and quantum-enabled satellites are requisite infrastructure for this. The combination of Australia's quantum, space and telescope expertise and capabilities presents Australia with a unique opportunity to develop (and provide world leadership for) the necessary quantum ground stations and miniature satellites that would form the basis for global quantum communications research.

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

UNSW also endorses the need for a national strategy for expertise development in support of Cybersecurity research.

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?

UNSW strongly endorses the strategy of bringing the national HPC facilities Pawsey and NCI under one governance structure.

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

UNSW endorses infrastructure investment in active and open data modelling and repository systems to broaden their scope and invite international collaborations.

As increasing volumes of data are captured in long-term storage, there is a need to adopt robust preservation policies and procedures. Australian research infrastructure would benefit from collaboration with international initiatives for digital preservation such as Archivematica (https://www.archivematica.org/en/). There are also emerging disciplinary-driven, collaborative financing models for Open Access, such as SCOAP3 (https://scoap3.org/) for particle physics.

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

A number of characterisation and analysis techniques have become so widely applicable as to be considered underpinning infrastructure. Likewise, micro-and nano-fabrication capabilities are of relevance across all national science and research priority areas. These techniques require a distributed national network of capabilities and expertise, open to all, and feeding in to the very high-end infrastructure and new flagships described under the research priority areas above.

- Microscopy and microanalysis is intrinsic to an extremely broad range of research areas, including medical sciences, cell biology, geoscience, materials and nanoscience, plant science, biological and soft matter science, as well as materials conservation.
- A fabrication capability for micro- and nano-scale devices and materials enables research and innovation in areas including advanced electronics, sensor technologies, energy generation and storage, medical devices and bionics.
- Nuclear magnetic resonance (NMR) finds application in medical, biological, environmental, physical and materials sciences.
- ‘Omics and associated bioinformatics infrastructure has become essential across the life sciences. As such it impacts on medicine, agriculture, environmental resources and

biosecurity as well as the applied biomedical sciences and biotechnology fields, and emerging applications in archaeology and paleontology.

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?

UNSW recommends that secure remote-access facilities for analysing linked public-sector data like the Secure Unified Research Environment (SURE) facility for health and medical data should also be established for other areas with sensitive data management needs, for example Indigenous research or National Security.

The emphasis on integrated research data solutions is positive, but the underlying standards and models need to be strong in order for an integrated system to work effectively. For example, it could be argued that ANDS services have enabled data to be discoverable and accessible, but interoperability and potential for reuse of data (including for replication of results/findings) are not yet as well supported. Open standards, and disciplinary metadata schema, which support rich contextual information, are necessary for research data to be effectively and widely re-used. As an example, UNSW, with NIF partners, is working on a pilot program with ANDS to develop protocols for data inter-operability in research imaging.

An area not addressed in the Issues Paper is data visualisation, which applies to health, medical, environmental and social data (also mentioned under Questions 20 and 24). Infrastructure for visualisation and analysis of large datasets should be supported and linked with 'omics, imaging, big data and eResearch as well as HPC. There is now a critical mass of leading data visualisation systems in Australia (such as the EPICentre at UNSW and the Monash Immersive Visualisation Platform) which are already building strong links internationally.

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

Significant international effort has been spent on initiatives for open standards and platforms, often by non-profit community-driven organisations. The Issues Paper makes references to the Australian Research Data Infrastructure Strategy (footnote on p. 46), and among the recommendations of this strategy document are open access to research data (R9 & R11) and data services that are flexible and adaptable, using standardised and open architectures (R14). Organisations working towards such goals include the Research Data Alliance (https://rd-alliance.org/), ORCID (http://orcid.org/), DataCite (https://www.datacite.org/), and the Centre for Open Science (https://cos.io/).

Australia should continue its role as a member of the International Neuroinformatics Coordinating Facility (INCF). Existing international imaging projects, in which Australia is engaged, include Enhancing Neuro Imaging Genetics Through Meta Analysis (ENIGMA, http://enigma.ini.usc.edu/), the Human Connectome Project in the US (http://www.humanconnectomeproject.org/) and the

BigBrainProject (https://bigbrain.loris.ca/main.php). A potential international project in which Australia could be a foundation partner would be extending ELIXIR (https://www.elixir-europe.org/) to link imaging data with genetic data.

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?

A general point about data for research and discoverability is that the strengths of existing open data initiatives could be recognised and leveraged to avoid duplication of effort. For example, implementing Linked Data frameworks for research content is one way in which libraries are currently contributing to and engaging with the wider information community. More broadly, engaging in international initiatives, rather than 'going it alone' will be increasingly vital, as identified in Q 34.

Data linkage is of immense importance, but there is real community concern about how data is identified and de-identified, how it is linked and how permissions are managed. Communities, particularly vulnerable ones such as refugees for instance, have even greater concerns. To ensure linked data is used safely, responsibly and ethically, data infrastructure investments should support an advisory body or council on the ethics of researching with linked data. Research communities should be supported to build on best practice in fields which have already addressed these issues successfully.

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 submission