# Submission
# 2016 National Research Infrastructure Roadmap
# Capability Issues Paper

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| **Name** | **Thom Dixon** |
| **Title/role** | **Project Officer (Research), Office of the Deputy Vice-Chancellor (Research)** |
| **Organisation** | **Macquarie University** |

## Questions

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

Macquarie advocates for a delineation between infrastructure that supports the sciences and infrastructure that supports engineering. Engineering is critical not only to the development of research infrastructure, but to the impacts and innovations research infrastructure creates. Fabrication facilities of high-end microelectromechanical systems (MEMS) based sensors and other devices would be one such piece of engineering-specific research infrastructure to consider.

An emerging capability area that has not been considered in the roadmap issues paper is that of virtual reality and simulation facilities. The acquisition and development of expertise within complex task environments is just one area of research that would benefit from such a virtual reality/simulation capability.

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

Governance is important to maintain clarity over national research infrastructure and the infrastructure that institutions (such as universities) seek to establish. Light-touch governance should ensure minimal duplication of infrastructure. Macquarie agrees that the governance characteristics captured in the issues paper are appropriate.

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

Macquarie strongly supports national research infrastructure investment assisting with access to international facilities. Macquarie notes that continuity of funding is often required to maintain preferred access and that discontinuity of funding can cause reputational damage at a national level. Major international programme membership ought not be conducted through project based grants but through targeted and strategic programmes that ensure the long-term viability of international access while also enhancing Australia's reputation and regard.

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

International facilities should be prioritised where they are: (1) the norm for doing top-quality research in specific disciplines, (2) not available in Australia, and (3) exorbitantly expensive to establish or maintain considering the likely national use of the facility. National facilities should be prioritised where there are national security imperatives or geographical considerations. In particular, when the infrastructure exceeds Australia's capacity to develop domestically (eg. a mature space program) then international facilities must be considered.

For data-intensive research, national subscriptions to international datasets may be far more cost-effective than grant-by-grant procurement. Health economics is just one example where large-scale international linked datasets are a core asset that would benefit from a nationally coordinated approach.

International facility access should be prioritised when it involves establishing a domestically located node that provides access to an international research network. The European Molecular Biology Laboratory is one such opportunity and example.

The establishment of Genome Foundries were prioritized as a foundational technological platform in the Synthetic Biology Roadmap for the UK (2012) [in attachments]. In 2016 we have seen the actualisation of five foundries located at Imperial College, Edingburgh University, Liverpool University, MRC Laboratory of Molecular Biology and a Genome Analysis Centre within Norwich Research Park. Within the US the two standout facilities are within private companies, Gingko Bioworks and Amyris. All of these facilities have extraordinary capacities for building DNA parts, testing functionality and the determination of optimal strains.

Although there international facilities are available for commercial use and potentially for collaboration, there is a need for a national facility in Australia. There are several reasons for this: our national biosecurity, ownership of intellectual property, international security concerns (dual use), and international biosecurity. Using an international facility for the generation of a functional bioproduct or strain is dependent upon the source country's policies on biosecurity. Australia's access to components of interest could be prevented if these components are viewed as too risky to transport or disseminate. Situations such as this have occurred in the past when the exportation of particular enzymes from the USA have been impossible due to US policy. Likewise, the importation of products or components classified as dual use are restricted by National Security concerns.

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

Macquarie believes that research workforce issues are inextricably linked to research infrastructure and that they cannot be considered separately. Investment in infrastructure should budget for a parallel investment in the workforce that will maintain and use the infrastructure and train other users. The workforce that supports and enables a piece of research infrastructure must be developed and supported across the lifetime of the infrastructure.

The human capital of research infrastructure – both researchers and research support – contribute to innovation and knowledge creation. Long-term infrastructure support staff are enabled to develop improved workflows, increase efficiencies, and innovate new applications for the infrastructure.

The national skills base is inherently reliant on a layer of research infrastructure that underwrites, attracts and maintains a national cohort of highly skilled technicians and researchers.

The increasing level of sophistication and novelty in technology and instrumentation necessitates an equivalent level of sophistication and cross-disciplinary expertise to program and operate the infrastructure. For technologies emerging in Australia, such as Synthetic Biology, there are a number of highly skilled molecular biologists and systems engineers currently working in the field. However, there remains a deficiency in the discipline for experienced and expert scientists. A highly-automated and robotic Genome Foundry would require expertise in fields such as software engineering, bioinformatics and automation engineering coupled with molecular biology and chemistry training. This skill set deficiency within Australia has been recognised by Macquarie University and undergraduate and postgraduate training is structured to fill this void through course design, the hiring of academics with these skill sets, and through targeted international exposure, such as through the international Genetically Engineered Machine (iGEM). iGEM is preparing the next generation of specialists even in the absence of a Genome Foundry in which to train the students.

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

It offers opportunities for staff, students and higher degree research (HDR) candidates to directly learn new skills in understanding and using state-of-the-art facilities while also providing opportunities for researchers to participate in projects and expeditions. Facilities network disparate but likeminded experts and technicians, and this coming together of minds, expertise and infrastructure creates the critical mass of know-how that generates transformative innovation.

National research infrastructure bridges academia and industry. Not only does the infrastructure provide technical apprenticeships for HDR candidates who will go on to work for industry, but the cross-pollination of multi-stakeholder use generates academia-industry partnerships and engagement.

There is a small pool of sufficiently trained staff available within Australia (and sometimes internationally) and this generates certain strategic imperatives. That is, the human capital needs of national research infrastructure are often met through informal apprenticeships. There is potential to formalise these apprenticeships in such a way to ensure long-term and systemically sustainable training pathways capable of long-term support for national research infrastructure. Macquarie advocates for an apprenticeship model whereby specialised training could permeate through the researcher and technician labour force.

Macquarie also suggests that national research infrastructure could offer travel sponsorships for local scientists to tour benchmark facilities available internationally.

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

Universities have a responsibility to provide their students and HDR candidates with baseline theoretical and technical skills that are considered essential to conduct research in their field. The emergence of transitional courses between bachelor degree and PhDs, such as the Macquarie University Master of Research degree, is a perfect mechanism for facilitating infrastructure-related training.

Research training degrees constructed to produce specific infrastructure related competencies will need to be coordinated in partnership with national research infrastructure in order to produce graduates with the necessary depth of training. There is potential for seamless HDR mobility when facilities host HDR candidates or universities host facilities.

Universities have a responsibility to develop and train their staff and this can involve raising awareness of the available research infrastructure and ensuring that staff are competent in the use of, and can gain access (travel, gateway portals, etc.) to, the facilities.

A Genome Foundry would be a highly-valued facility that would generate much interest from scientists from diverse fields. The facility would offer tours and short training courses on how to best capitalise and integrate the services available. The facility would also run student projects to enable exposure and conduct internships for undergraduates to increase their employability.

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

Macquarie suggests that that the principles underpinning access should take into account the qualifications, need, and demonstrated collaboration of user applications. Ultimately, access should be based on merit, however the ways in which merit is assessed will prioritise certain users over others. The principles underpinning access should ensure that users are not unintentionally excluded, and that the expenses associated with access are subsidised or offered at cost.

The assessment of merit should take into account career interruptions of user applicants as well as Early Career Researcher status. Both public sector and private sector users require access to national facilities and the principles of use need to find a balance between enterprise access (small, medium and large) and institutional access. Competition for the use of national facilities should not be around access costs, rather competition should be around meritorious use. Importantly, meritorious access regimes must balance the spectrum of research – from basic through to applied – while facilitating new user access and new programmes of research.

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

Macquarie believes that such criteria should take into account the national interest and national benefit. When assessing interest and benefit Macquarie suggests the following criteria: (1) the track record of national use and support, (2) the size of the user base, (3) the number of trained personnel, (4) and the quantity and quality of associated research outputs.

A more difficult set of criteria to implement would be impact and engagement assessments. Macquarie suggests that metrics linked to the national engagement and impact assessment may be of potential use as criteria for increasing/decreasing funding or decommissioning infrastructure, but this would require a reanalysis of such data in order to link it to the relevant national infrastructure.

Macquarie notes that the defunding and decommissioning of infrastructure is inextricably linked and that there should not be an expectation that national research infrastructure becomes self-supporting in the long-term. Macquarie suggests that the funding arrangements supporting the use of research infrastructure should from the outset have criteria that transparently displays when, how and why a piece of research infrastructure would be defunded or decommissioned.

Each item of national research infrastructure should be built with a corresponding funding strategy that covers all aspects of the anticipated lifetime of valuable use that the asset is reasonably expected to realise.

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

Continuity of funding is vital for national research infrastructure, particularly in support of operating, maintenance and replacement costs.

Macquarie notes that there is considerable variation between states as to the level of state support for national research infrastructure and that institutional co-investment is an important element, particularly when the infrastructure is hosted within an institutional environment or an institution's level of use is high.

Macquarie suggests that the potential location of identified capabilities needs to be carefully balanced such that the locations of critical masses of pre-existing human expertise are aligned with the sources of financial leveraging opportunities.

Macquarie notes that the Issues Paper says "in times of fiscal constraint, governments internationally are looking at new way to fund research infrastructure outside the traditional grants paradigm". Macquarie suggests that this fails to take into account globally low interest rates or note that it is currently an ideal time to invest in productive infrastructure from a financial point of view. Macquarie advocates that the Government look at the opportunities inherent in the current international funding environment and the potential that exists for investing in national landmark long-term productive assets. Macquarie endorses the role of the Government as an investor of patient capital as outlined in the Issues Paper.

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

Macquarie notes that this expectation is entirely discipline specific. Examples include: translational medical research and clinical trials (in order to meet TGA and similar, eg. FDA requirements), NCI coding requirements, and Auscope standards for geochemical analysis.

Macquarie also notes that cutting-edge research is often unique and beyond the remit of standards and accreditation requirements. A delicate balance must be maintained to ensure innovative research is not stymied.

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

Macquarie suggests the following examples: CERN (European Council for Nuclear Research); national laboratories in the UK, the EU and the USA; and the International Ocean Discovery Program (IODP). The UK Biotechnology and Biological Research Council (BBSRC) announced a consolidated investment in the emergent field of Synthetic Biology in January 2015 to establish a system of three integrated Synthetic Biology Research Centres and four Genome Foundries in response to the recommendations of the Research Councils UK Synthetic Biology Roadmap (2012).

Macquarie also suggests that space infrastructure is a very useful global model to examine. Satellite monitoring and positioning has impacted nearly every aspect of modern life and provides immense benefits to Australia in real time. Yet the country has no space program to coordinate activities in the sector. Over the next 20 years one of the most critical elements in successfully monitoring Australia will be whether or not the country has a central agency coordinating domestic activities and international collaborations in space infrastructure.

**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?**

Macquarie suggests that while it is not entirely comparable, lessons can be learned from the way ARC Centres of Excellence are managed at the end of their funding terms. Additionally, the Edinburgh Genome Foundry has been designed as a modular production line and individual units may be updated as required with minimal expense and interruption to the entire facility.

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

Macquarie suggests that CERN is one such example. Macquarie also suggests that NCRIS is a good model but that the lack of continuity in funding has been its principle weakness and the lack of mechanisms for engaging new organisations during the funding cycle would need to be considered.

## Health, Medical Sciences AND TECHNOLOGY

*Adding technology emphasises the end-user engineering aspects of the capability area which are not adequately covered in the Issues Paper.*

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

*5.2.3 'Omics:* Macquarie suggests that the field of 'omics is expanding beyond what is briefly mentioned in the Issues Paper. It needs to be clearly articulated that genomics alone does not reveal information about the chemical state of proteins and metabolites which are the functioning molecules causative of disease processes. Thus, proteomics and metabolomics are required capabilities to investigate causes and understanding of pathophysiology and health quality.

*NEW – Synthetic Biology:* The emerging field of Synthetic Biology is not mentioned in the Issues Paper. Capabilities in large scale DNA synthesis and assembly infrastructure are needed to rapidly produce and modify synthetic genomes/organisms for purposes more far-reaching than the Biologics capabilities outlined in the issue paper. Synthetic Biology offers the potential for new molecule development including antibodies, vaccines, pharmaceuticals and antimicrobial agents, and the production of new biological functions for diagnosis and treatment of disease and the engineering of organisms as therapeutic microbes. This capability exists at the intersection of ‘omics, bioinformatics, bioengineering and biochemistry and is also of critical importance to a diverse portfolio of research disciplines beyond Health and Medical Sciences.

*5.1.1 Big Health Data:* Macquarie notes that there is already an explosion of data associated with precision medicine and that this will only increase and become standard practice. There is a capability gap around infrastructure and training mechanisms that enable the integration of large-scale datasets with medical health records. Macquarie also suggests that imaging repositories be added to Big Health Data.

Macquarie points out the need for greater data access, more data linkage and much lower cost data. A lot of current health data is available nationally and internationally but is excessively expensive – this is a major limiting factor in research areas related to health systems, health informatics, health economics, public health, etc. Macquarie advocates for a national capability that addresses access issues.

*5.1.4 Imaging – Tracer Development; 5.2.6 Imaging; 5.3.1 National collaborative approach for PET tracers and cyclotrons:* Macquarie notes that the suggestion of coordinated tracer programs for imaging and therapy does not mention the need to give Australian researchers access to a development pipeline. For this capability to be successful it requires researchers to have access to the commercial, pharmaceutical and clinical expertise that bridge the high-cost (~ $1 billion) pathway towards clinical application. This is only going to happen through partnerships with industry.

Australia also requires and will depend on a pipeline of tracer production to enable clinical research and therapeutic trials. Without licensing agreements, commercial production capabilities or the associated human expertise Australia will lack this core capability.

One way to support this pipeline and a national collaborative approach for PET tracers and cyclotrons would be to build on existing research-focussed commercial operations. For example, Cyclotek Australia operates three cyclotrons in Victoria, one in Brisbane, one in New Zealand and is in discussion to operate the one beneath Macquarie University Hospital. Thus, Cyclotek soon will have a complete eastern seaboard presence for its production of research tracers to GMP standard. If this type of network approach were to be combined with a few existing research cyclotrons that are used for tagging and animal testing of brand new molecules, Australia would be well positioned to take greater global leadership in PET tracers and theranostic research, as well as in the clinical research and clinical trials that increasingly depend on the emerging generations of tracers.

*5.2.6 Imaging:* The inherent challenge in building national research infrastructure for the medical sciences is that it quickly goes out of date. It is important to dovetail planning with national research priorities and practical translation pathways. As an example, the procurement of 7T scanners for research – while displaying a much better resolution – will not necessarily translate into clinical practice as clinics use 1.5T or 3T scanners.

Macquarie suggests that human performance should be considered an important aspect of human health and supported with appropriate infrastructure.

One of the greatest challenges for Australia is the ageing population. Major international efforts are currently devoted to early prediction of cognitive decline and dementia. Sydney-based longitudinal ageing studies currently need to send participants to Melbourne for appropriate brain imaging. In the USA longitudinal studies have large funding combined with appropriate and coordinated infrastructure. It is far less coordinated in Australia and this should be addressed.

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

The Human Genome-Write Project was announced in June 2016, in a closed meeting at Harvard University, by a multi-disciplinary group of scientific leaders including Macquarie University's Deputy Vice Chancellor (Research). This project aims to synthesise the entire human genome to further understand the human genome and help develop transformative medical applications. As a member of the global Yeast 2.0 project, Macquarie University will be granted a position in the collaborative project if we wish to partake in what will undoubtedly be a landmark project. In this instance a high-throughput, heavily automated Genome foundry facility would be a necessity.

**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?**

Macquarie suggests that an Australian viral vector facility may be beneficial for generating custom vectors for biomedical research with the potential for translation into clinical therapies. Macquarie also suggests advanced magnetic resonance imaging facilities be considered.

NCRIS investments in 'Omics through BioPlatforms Australia has created capability on a national scale. Macquarie suggests that the 'Omics network of facilities requires a strategic upgrade to ensure it will meet the needs of the next 20 years.

The absence of Synthetic Biology as a capability area is a large and noticeable gap. Synthetic Biology spans a number of the broader capability areas in the issues paper. It is a future capability in which Australia cannot afford to delay acquiring the associated infrastructure.

Lastly, a national simulation facility would provide a world-first capability for researching human performance and should be considered.

## 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?**

Synchrotron and neutron light imaging of samples and experiments is a newly emerging area in Australian Earth Science – in many ways this is simply an attempt to catch up with world-standard.

Macquarie believes food and agriculture should be explicitly identified as a capability area within environment and natural resource management. 'Omics sciences already contributes to this discipline but the supporting national research infrastructure will need to be scaled up over the coming decade in order to underpin Australia's world-leading research in food and agriculture. If infrastructure in ‘Omics remains static across the next decade then Australian will lack internationally competitive capabilities required to exploit arising opportunities.

Macquarie advocates for the collection and storage of consistent data streams that provide a baseline against which changes in Australia’s terrestrial and aquatic ecosystems can be tracked across the decades. It should be recognised that the data produced by monitoring and observing may not necessarily be of immediate value or use to management agencies but that the value will accumulate over time, as temporal patterns emerge.

The clear gaps in present observing systems are coastal (including estuarine) and freshwater ecosystems, which presently fall between the scope of TERN and IMOS. Expansion of IMOS to support coastal systems research, including coverage of key estuarine ecosystems was one of eight key recommendations of the National Marine Science plan. Contrary to the claims of the Issues Paper, desert, tropical and alpine regions receive no worse coverage at present than other terrestrial ecosystems.

Macquarie advocates for the full use of national research vessels. This will greatly expand national oceanographic research capacity and properly utilise existing national assets.

Macquarie agrees with the emerging need for participation in international satellite missions and space missions in general. Macquarie advocates for the development of a centralised space administration within Australia that can coordinate national activities across multiple domains. Macquarie suggests that the absence of space sciences from the capabilities listed in the issues paper is an oversight.

Again, Macquarie recognises the role of Synthetic Biology technologies in areas relevant to Environmental and Natural Resource Management. Biosensors for agricultural pathogen detection, pesticide monitoring and water usage are some applications being developed elsewhere. The NSW Department of Primary Industry has partnered with Macquarie to develop such applications for Australian conditions. In addition, Synthetic Biology has potential for soil remediation and enhanced efficiency of contaminant sequestration using engineered microbe solutions. Such applications are dependent on the DESIGN-BUILD-TEST iterative process of synthetic biology technologies which are most valid if an automated, high-throughput technological platform is accessible.

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

In situ, high pressure experiments are one example. The USA-led COMPRESS consortium should be engaged with. There currently exists an opportunity for Australia to be at the forefront in various aspects of this research, eg. in situ XANES measurements of oxidation states.

Extensions to satellite gravity data from upcoming continuations of the GRACE/GOCE missions. Macquarie advocates for Australian involvement in interferometric synthetic aperture radar (InSAR) missions.

**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?**

Dedicated high-energy and low-energy end-stations on beam lines at the Australian Synchrotron.

Australia's continued involvement in the IODP should be assured. There is also a need to expand IMOS to include the inner shelf and coast. If both of these were done there would exist a national capability for integrated marine and coastal oceanographic observations and geoscience investigations. Such a network would probably require the standardisation of observational methods and research infrastructure.

### Advanced Physics, Chemistry, Mathematics, Materials AND TECHNOLOGY

*Adding technology emphasises the end-user engineering aspects of the capability area which are not adequately covered in the issues paper.*

**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?**

Macquarie suggests that battery testing capabilities, high voltage current energy sources for electric vehicles, optical fibre fabrications facilities, semi-conductor materials manufacture and micro-nano research facilities are all missing capabilities.

Macquarie notes that the 2011 Roadmap identified Nuclear magnetic resonance spectroscopy (NMR) as a key characterisation platform but that it is not mentioned in the Issues Paper. The Australian NMR network has already formed an operational National NMR Network. This network could be further activated and expanded through the acquisition of ultrahigh field (>16T) NMR capabilities. This would include spinning solid state NMR instrumentation and Dynamic Nuclear Polarization capacity. NMR infrastructure is at the forefront of Biology, Materials and Chemistry internationally.

Macquarie notes the opportunities that exist in harnessing Australia's biodiversity for natural product pharmaceuticals and agrichemicals including terrestrial and marine prokaryotes and eukaryotes.

Macquarie notes the importance of fabrication, characterisation and testing capabilities for new medical devices and technologies. This is a fundamental part of biomedical research.

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

Macquarie notes that the Australian Synchrotron currently has ~ 30% of its design capacity instrumentation and the OPAL reactor ~ 40%.  Access to international facilities is a critical supplement to these national facilities when they lack the specialised instruments required for specific measurements. In some cases this access will provide a medium term solution and provide Australian researchers with the experience in techniques that are to be installed at national facilities at a later date. Experience at international facilities proved invaluable in developing the scientific case for the instruments at the Australian Synchrotron and OPAL reactor, as well as informing instrument specifications.

In some cases Australian infrastructure (OPAL or the AS) are incapable of performing desired measurements, due to energy or time structure issues. Examples of this include access to Free Electron Lasers and Spallation Neutron Sources. For example, Total Neutron Scattering measurements can only be done using a pulsed neutron source, or by installing a hot source at OPAL. In other cases the demand by Australians for specialised techniques is insufficient to justify the investment in building a dedicated instrument at the National Facilities.

**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?**

Macquarie suggests that astronomical and space instrumentation should be considered.

Macquarie notes that there is no mention of a mathematics capability. Macquarie suggests that infrastructure in support of Australian mathematics should be considered.

Macquarie notes that the future of observation/NIR astronomy will be through space telescopes and therefore space science. Macquarie advocates for an improved capability in this 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?**

With regard to the emerging direction of innovation and translation Macquarie suggests that there should be a National Incubator to drive commercialisation.

Macquarie notes that the Digital humanities is not simply the textual analysis of documents, but any computer-enabled research from the humanities, arts, and social sciences. Supporting computer-assisted humanities research beyond textual analysis is of critical importance, e.g., regarding cultural heritage and archaeology. Other arts and humanities disciplines (aside from literature, linguistics, and archaeology) have particularly underdeveloped e-research infrastructure (and practice by researchers), offering a major opportunity for improvement.

Macquarie supports digital repatriation as a way of adding additional sources of data longevity. Viewing these communities as valued repositories of cultural data in general as well as honouring their access controls (see the Mukurtu platform for an example of cultural restrictions done well) is an excellent idea.

Archaeology, anthropology, sociology, linguistics, oral history, and other disciplines require infrastructure (and ongoing support of that infrastructure) for the collection, management, and dissemination of field-acquired data and have much in common with some field sciences (geosciences, biology, ecology, etc.).

Disciplines in this cluster suffer from the problems of diverse, heterogenous data. Small data has its own set of challenges and opportunities, but is often overlooked compared to big data. Outside of economics and finance, Understanding Cultures and Communities mostly deals with small data. The sort of infrastructure needed for small data includes access to, or training in, data modelling (since each project has to model unique data), software that is built for research but generalised and customisable, active and archival storage accommodating diverse data, data curation services, and domain-specific repositories. Federated architectures are generally to be preferred, to allow evolution of specific tools and provide sufficient flexibility, while also maintaining data interoperability. National support for linked open data datasets within open government initiatives can help provide the infrastructural basis for ontological mapping of small-science terms and datasets.

With regards to: "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," potentially useful and critical data to historical and archaeological research held by state agencies is often difficult to access and impossible to reuse effectively.

The *Future role of cultural and data institutions* section speaks of existing collections, but archaeology and cultural heritage, for example, are only now beginning to generate significant digital datasets, so data from these fields are not in any existing collection's remit. A Macquarie e-research infrastructure project had to discontinue a domain-specific repository in Australian archaeology, and merge its contents into an American repository, because long-term data curation infrastructure and services were not available in Australia at a sustainable price.

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

For archaeology and cultural heritage, Australia needs to look at the Archaeology Data Service in the UK as a model. The DINAA project in the USA also offers a model for sharing data housed in multiple state registers. Part of the problem of unavailable and poor-quality data in the state registers is infrastructure, but part of it is also policy. Ownership of data, licensing, and reuse terms and conditions must be developed and publicised, taking into account the sensitive nature of some data (especially but not exclusively Indigenous archaeology / heritage data).

**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?**

With regards to: "National and state cultural collecting institutions are a vital set of national research infrastructure to researchers", it is critical to allow these institutions to expand their remit. For example, state libraries should be encouraged and funded to capture topics of interest to the state, but also the outputs of researchers and research projects headquartered in that state regardless of topic.

## National Security

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

Macquarie agrees that Australia must maintain its own capacity in biosecurity. Synthetic Biology is not mentioned as a technology capable of offering biosecurity solutions. Macquarie has partnered with the Department of Primary Industries to develop biosensors for agricultural pathogens. In addition, Macquarie is a member of the steering committee of the CSIRO Future Science Platform in Synthetic Biology and fully supports the agenda to implement Synthetic Biology technology to control exotic pest species such as the cane toad. Yet, for efficient, globally competitive, exploitation of Synthetic Biology technologies for application to Australia's National Security, a highly automated, robotic genome assembly and testing facility is required.

Macquarie notes that space based observations will be important to support the water security capability. The GRACE gravity mission revealed more about Australia's variable hydrology than the last century of borehole monitoring. Groundwater monitoring is currently a fragmented approach and the data is not generally available. A coordinated and scaled-up approach would be very welcome.

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

International space infrastructure will be required in support of the listed national security research infrastructure capabilities.

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

Macquarie notes that energy security is not discussed nor listed as a capability. This is an important domain from a national security perspective.

Macquarie notes that 'internet of things' and wireless sensor network (IoT/WSN) research trends will bring with them national security challenges and this will need to be supported by the appropriate level of infrastructure.

Macquarie advocates for a national groundwater monitoring/modelling network with corresponding satellite data procurement.

## 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?**

IoT/WSN is an enabling technology that needs investment to stay at, and ahead of, world-standard. IoT/WSN based monitoring systems will be important for soil quality monitoring, water monitoring, environmental monitoring, structural health monitoring, etc.

Macquarie notes that geospatial infrastructure is serviced by the satellite industry. Macquarie suggests that this further demonstrates the need for a centralised agency coordinating these activities and that the overarching importance of space infrastructure to the Australian research effort should be acknowledged and strategically taken account of.

**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?**

Macquarie advocates for the discovery and recovery of research data (analogue or digital) and notes the possibilities regarding a national research data capability.

Macquarie would like to see more integration across different infrastructure facilities to allow better use in interdisciplinary research projects. There should be a transparent database of facilities facilitating easier and more efficient access to infrastructure.

## 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?**

Efficiencies of scale may be possible if international data are procured at a national level and access is coordinated through a national portal. The potential to improve Australian bargaining power in relation to international data should be considered.

**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?**

Macquarie suggests that the roadmap should consider the need to discover and recover already existing data. A problem at many research institutions across the country is that data exists in desk drawers, file cabinets and within hardcopy theses. Bringing these data online represents a huge wealth of research which has already been completed but is not usable in its present form. Making new data for research available and organising them into a linkable, searchable, sharable and extendable format is something that promises remarkable gains in which much of the expensive discovery work has already been completed.

Macquarie notes that most research data generated till now can probably be considered at-risk, either due to the risk of loss of data, loss of individual expertise, or the ever-present and burdensome need to update software in order to prevent security issues. There is no national strategy regarding data discovery, recovery and use that anticipates or plans for a 100 year future. Data is funded piecemeal and the legacy cost of maintenance is borne by institutions.

A national approach towards small and big data is required. It needs to be an approach that facilitates transparent collection, sharing and analysis. The digital resources being created now should be actively preserved for the use and reuse by future generations.

There is a large service component attached to research data and this needs to be considered as an essential component of the research data capability. This service component should encompass discovery, recovery, and curation. Across the near and long term, funding the service component of data for research will prove the most expensive component and the most important. Recruiting and retaining human expertise in this area is crucial.