2016 National Research Infrastructure Roadmap
Capability Issues Paper

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THE UNIVERSITY OF MELBOURNE

Introduction

The National Collaborative Research Infrastructure Strategy (NCRIS) forms the bedrock of Australia's research and innovation ecosystem, enabling world-leading, productive and pioneering research across the network of facilities. As an active contributor and participant engaged with numerous NCRIS-supported research activities, the University values the opportunity to participate in strategic planning and broad-based review of the assets, facilities and services underpinning Australia's national research effort.

The list of over 80 University of Melbourne contributors to this submission is at **Appendix A**.

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

We acknowledge the comments in the National Research Infrastructure Capability Issues Paper (IP) on page 12 that the trends and capabilities expressed in the paper are not intended to be exhaustive or prioritised, and note that the term 'capability' is used in the IP to cover both the headline focus areas, and current and emerging capability elements beneath those, plus (in some chapters) specific research infrastructure or research applications/technologies.

The University recommends **Agriculture and Food** should be profiled as a separate capability focus area given the significance of this domain to Australia's economy, environment and long-term prospects. Agriculture contributed around two per cent of Australia's GDP and 15 per cent of total Australian merchandise exports in 2013-2014. With the growth of Asia's middle-class and increasing demand for high-quality and value-added Australian agricultural products, agriculture has been widely identified as the next potential boom for the Australian economy. The Australian food industry, underpinned by agriculture, already accounts for around 20 per cent of domestic manufacturing sales and service income and could also be significantly scaled-up.

While aspects of food and soil research are touched on by three stated capability focus areas, relevant research is significantly broader than the mission-based disciplines covered under 'soil and water' or 'environmental change' priorities. Agriculture and food have profound relevance to research capability areas such as health, advanced technology and materials, and this should be visible in the next iteration of Roadmap capabilities.

We also suggest **Nuclear Magnetic Resonance (NMR)** deserves greater prominence across a number of the focus areas. For example, in biomedical science NMR spectroscopy has made substantial gains in the analysis of membrane protein structure and dynamics, particularly with regard to solid-state NMR; drug-lead discovery in fragment-screening; and in metabolomics, as a complementary tool to mass spectrometry. Australia lags in high-field fast-spinning solid state NMR capability and also in ultrafield solution NMR (>1 GHz) - infrastructure that falls outside the scope of ARC LIEF applications. Investment is essential to provide the necessary capability and skills at the chemistry-biology interface in pharmaceutical science, molecular biology, food and nutrition applications.

NMR is a swiftly advancing and globally competitive research field that will reward far-sighted workforce planning with economic gains. Building on our emerging strengths in NMR technology will have flow-on and cumulative productivity benefits in Australia, giving momentum to the growth of specialised workforces and deepening high–value export markets across a wide array of biological, chemical and materials science based applications, services and industries.

We also note an orientation in the Health and Medical Sciences IP chapter towards disease-focused aspects of health, omitting critical health considerations such as **Non-Communicable Diseases, Food and Diet**. The University encourages a broader definition of health and consideration of national research infrastructure (NRI) that underpins high-impact food research towards enhanced health and wellbeing and greater prominence of infrastructure that is essential to research linking human and animal health.

In the broad areas of fabrication and processing, the capabilities described in the IP do not sufficiently recognise the importance of **advanced manufacturing**. While Australia's economy is adjusting out of some low-cost manufacturing, there is a strong and growing market segment in complex, high-valued and specialised manufacturing in a range of materials and products. The 2016 Roadmap should consider infrastructure to enable that segment to build momentum in research innovation, thus opening up potential for further new manufacturing industries and productive alignment with national industry priorities.

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

Governance arrangements should be research sector-led in a broad sense, reflecting – as appropriate – co-invested stakeholders and the broader research sector such as RDCs, with industry involvement in governance of key facilities welcomed, where relevant. Sector-led governance arrangements will enable the development of coherent, discipline-appropriate management of NRI, including on strategic threshold considerations such as access models, or whether to invest in Australian facilities or enable access to international facilities.

Experience clearly demonstrates the need for multiple governance models to suit the varying NRI. Single site facilities, albeit serving nationally spread communities, have differing demands to those of multi-site or multi-nodal research investments. Governance arrangements should take account of disciplinary details; the impacts of geographic spread of research nodes; factors about decision-making and risk management; partnership independence; access arrangements (such as for industry and student researchers); and operational and investment relationships with other research structures (for example, host institutions or federations of State-based research networks).

The University recommends governance and oversight arrangements enacted at multiple levels:

(a) Individual projects need operational and governance arrangements to draw in relevant research community feedback on operations, utilisation and access;

(b) Depending on their characteristics, capability focus areas will be potentially require support from clusters of project-level investments. Cluster evaluations, to determine future directions, should normally occur on a 3-5 year cycle, varying with the volatility of change relevant to the NRI, and aligned with the committed capital and operational funding arrangements. While somewhat discipline dependent, an appropriate timeline should achieve a balance between currency and efficiency, in terms of the burden of the evaluation cycle on the research community or bureaucracy. Advance consideration of major and decommissioning evaluations should be part of the funding arrangements;

(c) In addition to anticipated periodic Roadmap cycles, there should be structured and regular review mechanisms to ensure optimal function of NRI, refresh program expectations and operational needs, and enhance connectivity across the research sector throughout Roadmap periods. For example, it would be valuable to have the option of holding back some dedicated resources within, and potentially across capabilities, to allow take up of disruptive technologies in the instance where these are not identified within a scheduled road-mapping exercise. As part of these periodic considerations, increased transparency, communication, cooperation and co-investment amongst Commonwealth agencies, States and institutions across Australia is required to minimise duplication and enhance the efficiencies and effectiveness of both the NRI and the research outcomes of meritorious researchers successful in the competitive grant schemes.

On a related note, we believe that a program for developing Landmark project proposals is warranted and estimate that, subject to maturity of the project, funding at 0.5-1.0% of the Landmark project funding being targeted would be required for their development.

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

NRI investment should assist with access to international facilities. The IP accurately outlines a number of the reasons why access to globally unique research infrastructure can increase the impact of Australia's research investment. The University is open to NCRIS investment in membership or subscription arrangements in the context of standing principles to be developed on criteria and models for subscription access. Enabling structured and principled access to international facilities has the additional benefit of building an Australian cohort of globally connected and experienced researchers who can advise on future domestic or international research investments.

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

The University recommends developing a process to establish: (a) high-level principles or criteria to be applied for determining investment in international access; and (b) a national body to make decisions on future international investments, drawing on the high-level principles and the advice and advocacy of the relevant research sector/discipline.

The national body should consist of experts from across research disciplines, working under a stated expectation that investment decisions will be made in consultation with research disciplines.

Factors important in prioritisation of international access or otherwise include:

- whether the access is a strategically important area of science and technology that aligns with national priorities and has potential to significantly advance Australia's breakthrough innovation.
- whether the critical mass of researchers and research expertise exists or is feasible of existing within Australia.
- whether the access has potential to train, attract and retain internationally competitive research staff, graduate students and expertise relevant to industry development.
- whether uniquely Australian data is required.
- whether international access can be supported from other funding sources (particularly non-institutional access such as through industry co-investment).
- whether the research outcomes would be of broad community benefit.

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

The IP rightly articulates the driving role of highly skilled and specialised staff within NRI. Research infrastructure workforce skills are a key national issue. Contemporary research across the breadth of disciplines is increasingly reliant on research infrastructure, digital literacy and data related skills. However, it is not feasible for graduate and early career researchers to have deep expertise in the myriad of enabling technologies, especially considering the rapid evolution of technology in domains such as genomics. Often researchers will use multiple technologies as required by the exploratory direction of their research projects. The ongoing training and updating of skills of end-user researchers is fundamental to maximising the investment in research infrastructure, complementing the outlay in the technical and specialist staff that are critical to the national research agenda.

Additionally, a great legacy of NCRIS to date is the development of skilled professionals who enable research and provide technical support. The research enabling workforce is as essential to the NRI ecosystem as the equipment itself, and as such it demands investment in workforce planning, career progression and employment security. The IP rightly observes that the demand for highly skilled technical and research staff has not been met by supply. In leading research countries overseas, professional research officers, such as laboratory engineers, are a well-established and secure role within the infrastructure investment ecosystem. Over recent years in Australia, many of these critical positions have become insecure short-term and contract-based roles, undermining confidence in and take-up of career pathways in these critical workforces.

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

NRI must include a deliberate focus and allocation of resourcing to training and skills development, rather than simply ‘assist’. There are two distinct but closely interacting cohorts for development. First, there are the end-user researchers that utilise research infrastructure. They need to understand broad technology concepts and be trained in optimal use of equipment and latest data analysis approaches. The second group is the technical staff and specialists that manage and drive technologies towards cutting-edge applications. Not only do the latter cohort require ongoing training on the technology front, they also require additional training and skill development in business administration, marketing, contract and intellectual property law, and financial and project management. This is particularly critical in light of the National Innovation and Science Agenda and renewed emphasis on building engagement between public research institutions and industry. Often access to enabling technologies within research institutions is a first point of contact for industry, and technical specialists can play a brokerage role in facilitating deeper partnerships between academics and industry partners. This is evident in the experience of CSL Ltd, which now works closely with the University of Melbourne-hosted node of Metabolomics Australia.

The University recommends an NCRIS-led development of a research infrastructure technical and specialist staff framework that can be applied to local enterprise bargaining agreements of research institutions, supporting a people strategy that is sustainable and enhances recruitment and retention through provision of ongoing career development opportunities. NRI can support training and skills development of both cohorts by explicitly allocating resources to these activities and affirming importance by setting applicable key performance indicators. The emerging blended workforce of business managers and technology/academic specialists could benefit from a national fellowship program and hence the 2016 Roadmap should consider how NRI more deliberately aligns with the two national funding councils. It is an opportune time to have a national conversation about this workforce, and consider a medium to long-term plan that addresses career pathways and workforce supply.

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

Research institutions have an integral role in developing infrastructure ready researchers. However, capacity to do so is dependent on the organisation's ability to access current and future researchers. For example, in the data domain higher education providers are best placed to provide the technology grounding through undergraduate and masters-level training (for example, Master of Science in Bioinformatics), whilst the entire research sector builds on this initial foundation at the PhD- and post-doctoral level. As another example, there is an urgent need for staff specifically trained in the capture and preservation of performing, visual and creative artefacts. New research degrees to encourage and build capability in young researchers for digital humanities could be considered, following examples such as the M. Phil in Digital Humanities and Culture offered by Trinity College Dublin in the UK.

Research institutions have responsibility for shaping syllabi and delivering content that reflects contemporary research and national priorities. Research institutions also have a major macro-level responsibility in tracking and responding to the skill sets being developed by students and early career researchers within their institutions. On the other hand, specialised training that promotes development of researchers who are working at the forefront of research infrastructure technologies, including informatics skills and data literacy, should be a shared burden between research institutions and national research infrastructure (i.e. NCRIS).

Research institutions can do more to acknowledge the technical specialist roles within their human resource structures and to be purposeful in supporting career development and advancement opportunities, such as by proactively tackling hurdles that exist within current enterprise bargaining agreements. For example, at the University of Melbourne we have utilised a job family of 'Academic Specialists' in appointing a number of platform technology staff. These Academic Specialists have fit-for-purpose key performance indicators that are different to what would traditionally be expected of an academic. To date the University has promoted such a specialist to the level of Associate Professor. Nevertheless, challenges continue to exist as a result of the 'academic' versus 'professional' staff dichotomy, acknowledging that many technical specialists are not PhD qualified and yet contribute immensely to the research enterprise.

A fragmented approach, in which each research organisation adopts varying initiatives in supporting this workforce, is detrimental to the sector, particularly considering the equitability issues that will come with multi-nodal NRI. Whilst acknowledging there is a research institutional responsibility to develop the technical specialist workforce, it is imperative NRI demonstrate leadership (with due consultation) in setting principles and providing direction on the development of a framework that guides the sector in this regard.

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

The University recommends the development of equitable, transparent, open access-oriented principles to managing access to NRI. In the University's view, the tripartite delineation of access or 'prism of accessibility' outlined on Page 9 of the IP does not accommodate the full array of infrastructure investors, researchers and end-users of research (such as members of the public, individual academics, institutions, organisations, business, or mixed research entities, such as CRCs) and circumstances in which access may be sought. As such, the principles that underpin access to NRI should encompass a wider range of blended access models, with a higher degree of flexibility to cover co-investment by institutional or other investors.

The University recommends against a one-fit or homogenous model of access by researchers and other end-users of research to NRI. The principles to be developed could include a mechanism to moderate geographic bias, for example through enabling offsets for travel to access infrastructure. Merit-based access should always be made available. Subscription-based access may be feasible in some circumstances.

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

The criteria and funding arrangements for deciding to defund or decommission should be clearly set out as part of the governance arrangements for NRI (see our response to Question 2). The University's view is that the life cycle of NRI instruments would be significantly improved through more regular and structured reviews functions built into governance arrangements for NRI instruments and programs. The review cycle would enable incorporation of up-to-date discipline needs and linkage to long-term planning and strategy for the capability area. By establishing a proper review cycle, the governance arrangements covering defunding or decommissioning could include: a) the setting of expectations against capability and international benchmarks and b) monitoring and assessment against those expectations. It would take into account discipline or mission based factors, such as computing infrastructure with a three-year half-life, or the impact of strategic investment enabling the NRI to be absorbed into business or institutional operations.

The University notes that national research facilities in the United States (US) are defunded on a semi-regular basis. A close look at the process used in the US and the criteria applied may assist development of appropriate Australian guidelines for defunding or decommissioning. Practical considerations may include, but are not limited to, the following: obsolescence or cost reduction of NCRIS technology; a sustained drop in the level of usage; insufficient user demand for access to the equipment (for example, due to new alternative technologies); non-competitiveness of research data produced by the equipment; inadequate maintenance or insufficient support for periodic upgrades of the equipment; or inadequate expertise to operate the equipment at internationally competitive standards.

In developing criteria for defunding or decommissioning, it may be equally important to consider arrangements for securely storing and archiving research data, rather than losing or destroying it. Even the most eminent sector leaders today cannot second guess future research needs and questions.

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

The University supports on-going and sufficient public investment in NRI across all capability areas as a fundamental public good. Investment in nationally crucial research infrastructure at scale cannot solely be met by either research institutions and/or industry. NRI broadly supports discovery research, which by definition is too risky for wide commercial investment. Nowhere in the world do expensive, high-end operator dependent facilities work in a cost neutral way, whether by research institutions or by industry. Industry and research institutions can make meaningful contributions to build and sustain an effective national ecosystem of research infrastructure. However, the 'market failure' aspect of discovery research requires government intervention as part of the broader innovation agenda of Australia.

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

Standardisation is important but not at the expense of the ability to conduct cutting-edge discovery research. For example, National Association of Testing Authorities (NATA) accreditation of facilities can prevent pushing the boundaries of instruments due to fixed settings linked to standard operating procedures. Therefore, in the design of national research infrastructure, standardisation and related accreditations must be fit-for-purpose for specific capability areas, best served by complementarity across multiple national nodes.

Given that the administrative burden of standards and accreditation can be onerous, costly and restrictive, the University recommends that capabilities should only be expected to address standards and accreditation requirements in appropriate contexts. It is already well-established in the operations of research entities that part of the research investment is to support research across sectors. Where there is a clear need and supporting business case for the research undertaking to achieve relevant industry benchmarks or accreditation of process, these costs should be costed and incorporated into the NRI funding. The achievement of relevant standards and accreditation should not be taken as a uniform requirement; rather, it should depend on the context of the NRI capability and the characteristics of the end-user base.

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

In looking overseas for best practice examples, it is pertinent that some models adopted in Europe or in the US operate at scales unlikely to be achievable in Australia. While there is no one-size-fits-all model of best practice, strong examples exist within research disciplines. For instance, an effective collaborative model is that of national platform consortiums, such as Genome Canada, which has similarities with the NCRIS-funded BioPlatforms Australia.

A best practice model for national investment in institutions that merge leading research capability with collaboration and research training is Cold Spring Harbour Laboratory in the US. The Cold Spring Harbour Laboratory is highly-regarded for its cutting-edge laboratories and research outcomes, as well as its contribution to the national research ecosystem as a centre of learning to the retention and professional capability-building of scientists. In a similar vein, strong practice models are observable in mathematical science institutes such as Mathematische Forschunginstitut in Oberwohlfach, Germany; the Science Centre for Geometry and Physics in Stony Brooke, USA; the Mathematical Sciences Research Institute in Berkeley, USA; the Banff Research Station in Canada; and the Newton Institute in Cambridge, England.

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?

As commented in the response to Question 9, the US model of defunding and decommissioning warrants investigation.

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

No response.

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 needs?

Overall the emerging directions and NRI capabilities identified by the IP resonate with the University's views. We suggest that translation in itself is not an emerging direction but rather an output of research excellence. Research infrastructure that enables **clinical trials**, from patient recruitment and accommodation to biostatistics and health economics, will play a pivotal role in translating discovery research into clinical application. It is our recommendation that there be nationwide research infrastructure investment in this area, targeting precincts of biomedical and clinical research critical mass.

The term 'health' is predominately linked in this chapter of the IP to disease. However, **non-communicable disease impacted by food and diet** is missing despite having a significant social and economic impact. The University encourages a broader definition of health and consideration of research infrastructure that enables food research towards enhanced health and wellbeing.

Additionally, the international positioning of the **One Health Initiative** points to greater prominence of infrastructure that is essential to research linking human and animal health. For example, we strongly endorse investments in **biological containment** infrastructure to handle the global challenges of highly infectious diseases impacting both humans and animals.

Structural biology and underpinning enabling technologies such **cryogenic electron microscopy** and **Nuclear Magnetic Resonance (NMR)** will be key investments of the future, playing a critical role in characterisation and subsequent drug therapy development. Similarly, Magnetic Resonance Imaging (MRI) and Positron Emission Tomography (PET) technology is rapidly evolving, and in the case of 7-Tesla MRI, there is unprecedented levels of imaging resolution opening the door for enhanced early diagnosis in Alzheimer's and Multiple Sclerosis.

In the case of clinical imaging, it is imperative these technologies are complemented with tracer development that advances novel detection and diagnosis capabilities. Strategic geographical positioning is key to ensure availability across the federated bio-imaging research infrastructure, noting the limited half-life of the tracers. Collectively, these complex instruments are both expensive in capital outlay as well as maintenance, and yet critical for discovery research and clinical therapy, ultimately resulting in reducing the strain on the health care system. One example is the development of further imaging capability to complement the proposed Proton Beam Therapy (PBT) machine to be located in Parkville, towards the development of which the State has currently committed $50 million. A full business case to assess the capital and operational expenditure requirements for the clinical and research facility is under development by the State. To position Australian researchers as international leaders in this emerging field, and building on our existing strengths in medical physics that have attracted significant investment from global industrial partners, investment in a dedicated PBT research gantry would leverage the state funded clinical facility, and create research opportunities that will impact on clinical applications.

Cellular therapies, based on pluripotent stem cells or antigen-specified targeting (e.g. CAR-T), offers the possibility of the scalable manufacture of therapies for regenerative medicine. Extensive international collaboration will be required around issues such as determination of the optimal homozygous human leukocyte antigens (HLA) panel, donor selection, screening and consent, good manufacturing practice (GMP), standards and quality control and regulatory legislation. Australia is severely lagging in this domain. For Australia to effectively participate, there needs to be investment in establishing GMP-certified induced pluripotent stem cell (iPSC) haplobank infrastructure, thus supporting the development of new modes of therapy.

Akin to haplobanks, **biobanking infrastructure** (i.e. tissue collection) requires further national investment. It is critical to enabling cellular therapy as well as application of personalised medicine through 'omics' research. Investment in the enabling research infrastructure will not be fully realised unless the jurisdictional challenges of access to biobanks and related clinical data is made available under common national standards (informed by international best practice).

The IP briefly and narrowly captures the capability potential of omics. Omics is more than genomics and extends beyond personalised medicine when one considers the role of the omics in food research and subsequent interventions applied to health and wellbeing. The University recommends the Roadmap adopt an **integrated systems approach to omics**, including the development of emerging areas such as lipidomics to complement the existing national strengths in metabolomics, proteomics and genomics. An ongoing need is bioinformatics capability, where further NRI investment is required to facilitate the curation, analysis and development of tools to address the copious amount of data, and ultimate translation of research.

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

Big data analytics and systems approaches to tackling global challenges is now the norm, and there is an ongoing need to ensure Australia participates globally through membership in initiatives such as **ELIXIR**, as discussed in our response to Question 31.

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?

An enduring barrier is **access to clinical data**, noting the inconsistencies and lack of harmonisation across a myriad of divergent local policies and practices. As we recently documented in our submission to the Productivity Commission's inquiry into data availability and use, the University calls for COAG-led whole-of-government collaboration to progress foundation reforms, funding architecture and streamlined governance arrangements to support access to crucial data for research such as clinical data. An appropriate government policy response must be underpinned by investment in appropriate infrastructure, as is occurring in international jurisdictions. Such investments involve physical infrastructure, and obviously expertise in data curation and management, but also essential is the technical and governance infrastructure to provide secure, granular authorised access integrated with agreed privacy protection principles.

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 needs?

As noted in the University's response to Question 1, ensuring infrastructure investment in **Agriculture and Food** is of national significance. The IP does not cover research capabilities that are critical to protecting Australia's ecological and economic future, such as soil conditions, microbial change, vegetation change or food production technologies beyond the farm gate.

Agriculture is entering a new technological era, increasingly utilising super-computing, shared data platforms and linkage infrastructure. **Precision agriculture** such as virtual labs, virtual farms, wide-spread crop sensors for livestock and crop health and performance should be seen as an emerging capability that will have significant impact on future Australian export industries and productivity, and hence, a compelling basis for considering relevant NRI demands as part of the 2016 Roadmap process.

Understanding the intersection between human, animal and environmental health and welfare is related to Australia's role in the **One Health Initiative.** This is a pivotal emerging capability globally, and relies on well-supported local infrastructure at a national scale. The Australian Animal Health Laboratory is a hugely important resource to the nation and plays a crucial role in protecting the agricultural sector and animal production industries. We strongly endorse the maintenance of this existing infrastructure.

National scale monitoring of ecological changes to Australia's land mass is a missing NRI capability relevant to this chapter. Australia is prone to extreme events (bushfires, cyclones and floods) and draws heavily on environmental and ecological resources for food production and trade. Currently there is inadequate resourcing for monitoring and cross-verification data for numerous ecological trends – vegetation change, population growth, invasive species, carbon fluxes in soil and specific vegetation types, pollution, and factors underlying these – all of which will require significant monitoring infrastructure supported by satellite data, *in situ* validation and calibration. Existing remote sensing capabilities currently available are inadequate at the national scale, and where state-based monitoring does occur, such as pollution monitoring, there is currently no national coordination of data.

Another important emerging capability that deserves consideration in the Roadmap is **carbon profiling in soils, soil microbiology and chemistry**. In future years this capability will require NRI far beyond the collection of data via satellite remote sensing and unlinked weather stations. For example, automated and linked-up soil moisture stations in farms and other sites will be core research infrastructure requirements, supported by sampling conducted by people and subsequent analytical chemistry. Europe has started investing heavily in soil profiling, but not all of this research is adaptable to Australia's unique ecological conditions.

National scale monitoring will require greater capability in **integrated modelling of biological and environmental data**, backed by supercomputer infrastructure, consistent linkage of geo-referenced datasets, sufficient resourcing for longitudinal monitoring and trained technicians and researchers working with the data. The IP picked up on the theme of integration in its comments on the possibility of future 'ecosystem observatories', created through coordination and integration of ‘omics fields. While environmental modelling is well-integrated *between* disciplines, there is currently a gap in NRI to support integration of environment modelling *across* disciplines.

The University observes that some of the existing technologies included as ‘existing infrastructure’ will remain critical NRI over the 2016 Roadmap years and beyond. As an example, the **ACCESS modelling capability** is essential NRI that requires sufficient maintenance and support for the equipment, the professional research personnel and training systems.

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

The **Climate Model Inter-Comparison Project (CMIP)** is a standard experimental protocol for studying the output of coupled atmosphere-ocean general circulation models, of which Australia is the only Southern Hemisphere node and hence of international significance for continued support.

Australia should consider a coordinated effort to participate in the **Agricultural Model Intercomparison and Improvement Project** (**AgMIP)**, a major international effort linking climate, crop and economic modelling communities with cutting-edge information technology to produce improved crop and economic models and climate impact projections.

Australia should also adopt a leading role in establishing international research infrastructure collaboration on **Antarctic research**, which (along with the Southern Ocean) is not adequately monitored despite the rising problem of glacial melts, ocean warming and darkening reflections. At present, research data lacks sufficient reference points with continuous observations for validating the data. Australia has a geographic interest in changes in the Antarctic, along with analogous countries who could collaborate on research and monitoring infrastructure networks such as Chile, New Zealand, Australia and South Africa, to mirror the work already well underway amongst Arctic counties.

Herbarium specimens are a significant resource contributing to research globally on mapping, biodiversity, ecological research and environment niche modelling. National efforts through the Atlas of Living Australia and the Australian Virtual Herbarium contribute to global research in these areas. Australia could look to more actively participate in international efforts such as the London-based **Global Plants Initiative**.

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?

No response.

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?

NRI investment should consider emerging directions in **quantum measurement** in addition to precision measurement in advanced physics. Technological advances and increased capability for these measurements, including new forms of sensing and measurement based on quantum effect and low temperature measurement are emerging nationally, albeit in a fragmented manner. This is now reaching the threshold activity that would benefit from consolidation, national coordination and the opportunity to team microscopy facilities with quantum measurement.

The IP paper identifies **minerals processing** as a missing capability. A nationally accessible research facility would give Australian researchers the ability to conduct research and chemical production at the same scale as minerals processing companies, such as through the compounding of minerals. Currently, academic researchers cannot access this level of industry processes.

In the area of fabrication, a missing capability is **theoretical materials design/computation**, which underpins fabrication and characterisation. Australia needs a NRI facility hosting high-performance computing infrastructure, facilities and supporting personnel to build a national capability in computational nanotechnology research, education, and collaboration. A useful infrastructure model to look to here is nanohub.org in the US.

The fabrication and processing capabilities described in the IP appear to pay insufficient attention to the large realm of **manufacturing**. While Australia's economy is adjusting out of some low-cost manufacturing industries, complex, high-value and specialised manufacturing in a range of materials and products remains a strong and growing market segment. Investment in materials fabrication can open the doors to new advanced manufacturing industries, create jobs and create a natural outlet for Australia's growing start-up ecosystem. Having the right NRI, such as prototyping facilities, to support and sustain that research and innovation in this space should be a consideration in the 2016 Roadmap.

Mathematics is an essential underpinning capability to many areas of research and innovation. The Australian Mathematical Sciences Institute well serves the function of education and advocacy but the new methodologies that are unlocking data and applications come from research. The capabilities to be articulated in the 2016 Roadmap capabilities should support the Mathematics Decadal Plan's recommendation of establishment of a **national research institute on mathematics**, from where intensive research and collaborative research programs can be led. Future NRI investment could be targeted towards scaling up and guaranteeing existing research infrastructure currently hosted at the institutional level, such as the University of Melbourne and Monash University's partnering to establish the MATRIX mathematical research institute, currently hosted in the Victorian regional town of Creswick.

A globally emerging capability that is missing from this chapter is national investment **micro-satellites (CubeSat) technology**. This rapidly evolving and potentially disruptive technology is transforming accessibility to atmospheric and space research with wide-reaching applications across astronomy, biological and physical sciences. A key component of this research and technology development is a suitably expert and skilled workforce with opportunities to be leveraged from international efforts within research institutes across the US, Europe and Japan.

The 2016 Roadmap capabilities should also consider Australia's role in the quest to detect dark matter through investment in an **ultra-low background radiation underground laboratory**. The quest to detect dark matter is a global enterprise. Australia's unique characteristics in the Southern Hemisphere would enable a unique and specific capability in this area. Several advanced countries have a deep underground lab sheltered by a cosmic ray, enabling a vast range of fundamental and applied science. Many areas of research application and experimentation, including physical, astronomical, material and life sciences, would benefit from a research facility shielded from background cosmic radiation unavoidable at sea level or above. A laboratory deep underground (more than 800m) would be ideal to house sensitive experiments in emerging capabilities such as dark matter detection dark matter detection, neutrino-physics, geophysics (muon topography), materials science (high purity materials and purification systems) and astrobiology.

Reiterating the University's responses in earlier chapters, **high field NMR** should be captured as a necessary NRI capability. While Australian researchers currently travel to the US or Europe to access instruments that are not available in Australia, building capability in our country would allow Australia to stay at the forefront of research and open up availability to a far greater field of Australian users.

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

Australia should continue to be engaged in global research appropriately tagged as Landmark such as SKA and LIGO. The University notes that the scale of these projects makes them unsuited to NCRIS investment. It is important that they should be considered quite distinctly as landmark infrastructure.

Australia's NRI should support engagement with the **European Union (EU) Human Brain Project** and the **BRAIN Initiative** in the US. These are very large projects at the forefront of emerging technologies and to date it has been challenging for Australian researchers to be able to play a part. Participation relies on sophisticated imaging resources such as those supported by the National Imaging Facility which has been hugely positive and has promoted world-class brain research.

As indicated in question 21, while access to international deep underground laboratories is important to the advancement of Australian fundamental and applied sciences, there are opportunities to complement international activities with local investment in a national underground laboratory resource.

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?

In relation to the trend of convergence covered by this chapter of the IP, the University observes that encouraging the emerging linkage between physical disciplines will have significant impact in coming years. Examples of this are the relevance of fabrication to astronomy infrastructure and high performance computing, and collaboration between mathematics, physics and chemistry. While the IP treats these disciplines separately, the catalysing collaboration and converging of research fields could be viewed as underpinning research infrastructure.

The University strongly endorses the IP's statements that where appropriate, NRI should support interaction between disciplines and the industrial sector. The ability to rapidly prototype in a cost-effective and timely manner in Australia is missing, especially in the medical devices space. In that space, convergence has been a key theme for many years, which should be extended to the physical sciences. Overseas models to be looked at for this include the **Innovation Collaboration Centre (C2MI)** in Canada, and **CMC microsystems** in Canada.

The IP comments on page 28 that development of national translational capacity to bridge the gap between scientific research and fabrication of prototype devices through access to scaled-up facilities is a key priority. Linked to this, an enabling infrastructure to build this translation capacity would be the establishment of a **databank or repository of advanced modelling software licences**, such as Cadence, made available Australian researchers in a similar manner to the licences currently made available by libraries to databases and journal subscriptions. Access to such licences could be negotiated and managed by an NCRIS steering body. This would support national access to critical enabling tools in an equitable and cost-effective way.

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 University endorses the focus in this chapter of the IP on building digital resources and enabling better access to them. As has been successfully applied in various science disciplines, we encourage recognition of the value of NCRIS investment in providing Australian scholars access to resources internationally, where these have unique and relevant characteristics.

Existing resources like the **National Library of Australia's Trove,** and the SuperScience then NCRIS-funded **AURIN** Project, firmly demonstrate that the significant up-front cost returns lasting value by opening up new research methods and paradigms, and also gives tangible improvement in the efficiency of research. Related to this, the 2016 Roadmap's focus on digital capability should include capability and resourcing for **digital preservation, digital forensics and digital salvage**. A significant proportion of held resources are analogue and will require a coordinated national, scaled-up approach to digitising before analogue machines become irreparable.

An NRI capability that is not fully captured in the IP's description of emerging and current capabilities in the IP is **linkage and connectivity of research infrastructure** to support collaboration and searchability across research and cultural sectors. A deeper capability for integration and linkage would build on the NRI capabilities expressed in the IP under 'digital humanities and digital repatriation' on page 32 and 'national and state institutions' on page 33. For instance, appropriately anonymised and secured, linking of key publicly held databases, such the ARC, the Australia Council, the ABC, the Department of Education and Training, AusStage and AusLit would create a powerful research resource that could be exploited to enable greater understanding of cultural productivity, demographic trends and cultural participation (for example, music training) across Australia.

Similarly, the University affirms the IP's comments on page 33 on integrating and harmonising national and state cultural and data holdings. Even where distinct data holdings are well-developed and widely utilised, NRI capabilities currently lack linkage. Examples where NCRIS investment would generate research value include linkage across national film and sound archives, media infrastructure (especial remote media and indigenous media), cultural assets (such as song and dance recordings) and the International Association for Translation and Intercultural Studies (IATIS). As a further example, sharing resources between **national and international jurisdictions on ranger and wildlife programs** would enable researchers to break into new realms if, for example, Australia ranger databases were linked with trawler records, fisheries and Border Force (where appropriate), community organisations and wildlife mapping resources.

Similarly, current capabilities in the IP do not provide infrastructure to collect, preserve and document thousands of hours of **indigenous culture, language and audio recordings** that are currently held in remote media holdings and libraries. An essential component of infrastructure investment is in the protocols, recognition and search platforms, enabling the research use of unique and irreplaceable resources such as these. Another example is infrastructure capability to house and manage collections of consent-based and secure **indigenous genomics**. Research institutions currently hold vast collections of indigenous DNA that could provide a baseline map of the indigenous population.

The University strongly encourages that the indigenous research platforms capability elements outlined in the IP in this chapter should also be picked up in the Health and Medical Sciences domain in the Roadmap.

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

The Galleries, Libraries, Archives and Museum (GLAM) sector is deeply engaged in how wireless digital technologies can enhance and expand their audiences' experience of their physical and digital collections and exhibitions. Future NRI should enable collaboration around **cultural image resources** stored at high resolution. This capability should extend to a one-stop-shop cultural image platform for all art forms – images, video, 3D, virtual reality – with appropriate copyright management arrangements. A relevant example of this is ArtSTOR with its IAP collaboration with key art institutions.

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?

The Roadmap should consider **prioritising research engagement with Asian countries** in the burgeoning digital humanities space, within academia and within public and private cultural institutions, like museums, galleries, libraries and archives. Given Australia's geographical location and migrant demographics, effective research engagement around digital humanities and creative arts initiatives in Asian countries will be critical in coming years as the cultural, research and academic infrastructures in those countries expand.

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 addition to the capabilities captured by the IP, there is also emerging need for NRI capability on **biosecurity investment on endemic diseases** and therefore on facilities at lower containment levels. The national cost of incomplete containment of these diseases is an ongoing imposition on agricultural productivity but is overlooked in comparison to exotic and emergency diseases.

A capability omitted by the IP is **animal health security,** which has strong ties to human health security. As discussed earlier in this submission, AAHL is an important infrastructure with a crucial role in protecting the nation's health security. The University strongly endorses continued investment in animal health security and ensuring capability to conduct high-risk observation of infection diseases through autopsy and other methods. Existing research work on animal health security would be enhanced by improved physical infrastructure integrated into NCRIS, such as a new quarantine facility and laboratory infrastructure for post-entry animals. Additionally, there is need for NRI planning to consider opportunities for supporting joint research initiatives and capacity building project links between existing infrastructures nodes. For example, Metabolomics Australia is beginning to work with AAHL on shared research inquiries that will expand the capacity of the respective clusters.

Another capability warranting greater focus is **mechanical security**, a crucial part of the national security mix. NRI instruments that can provide the base for large-scale experiments such as wind tunnels, water tunnels and centrifuge would enable researchers to understand the impact on humans of high-pressure or high-scale conditions. In a similar vein, there is an existing NRI gap in machinery to test network control systems, such as test beds for electricity. These sorts of infrastructure are critical to national security to undertake the controlled testing that ensures critical infrastructure (water, gas and electricity networks) will remain operative and resilient under attack or environmental instability. In comparison with other countries, such as the US, Australia lags in research infrastructure for security testing of this kind.

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

As noted above, Australia's public NRI lacks the capability to test either the security of electricity networks (grids) or the network and communication protocols that sit on top of that to manage the network. Australian research on national security would be most benefited by a mix of local investment in capability by establishing **network control system test beds in Australia** linked with internationally collaboration on larger scale testing platforms.

Australia would benefit from drawing on and contributing to the US DARPA's datasets on internet traffic and access patterns, which are able to capture normal usage as well as traces or simulations of traffic and access patterns in the context of online attacks. These traces become **benchmarks** for future testing, detection and security systems. There could be a key role for NCRIS to enable a middle entity to generate benchmarks through collaboration with Australian organisations and US infrastructure to establish a stronger security testing capability in Australia.

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

A consideration for the 2016 Roadmap on national security capability should be **interconnectivity**, meaning a research base on the flow-on security consequences of cascaded failure if one or more networks are attacked or fail. The University also wishes to affirm the importance of the comments regarding the importance of a **coherent national cyber security capability** on page 38. A national capability should be capable of leading the response to attacks in real time, by tracking the attack, coordinating the response, and effectively integrating the information with other agencies. While there is an equivalent organisation in the US, Australia's only joined-up and authoritative infrastructure in this regard relates to the limited role of authentication and permissions.

Underpinning Research Infrastructure

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

The IP includes primarily physics- and computing-based NRI as underpinning research infrastructure, but omits others that are underpinning on the basis of their critical underlying linkage to a range of research efforts. For instance, while neutron and x-ray scattering has been included in this IP chapter, the 2016 Roadmap should include other foundational research infrastructure technologies and data generating platforms such as 'omics and microscopy.

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

It is essential that NRI investments in this domain facilitate international collaboration to elevate Australian recognition and enhance linkages with international science platforms. International engagement should not be limited to Australian engagement with overseas infrastructure, but should encompass international access to Australian research infrastructure where this can enhance the impact of collaborative research for Australian researchers.

The **ELIXIR program** provides one example of the value generated by international linkages. ELIXIR, the European infrastructure for biological information, is building a portal to bioinformatics resources world-wide. The NCRIS-supported EMBL-ABR capability is currently collaborating with ELIXIR and others in the collection and dissemination of Australian bioinformatics tools as well as broader tools of relevance to Australian life science researchers. NRI investment in international initiatives such as this will ensure that Australian researchers can contribute to the design, development and innovation that occur through the development of digital research platforms, in addition to collaborating on usage to facilitate increased international linkage of data.

Other examples of international projects with which Australia should further engage are: **Genome Canada**, a pan-national life sciences consortium focused primarily on informatics but also metabolomics and training; the **OpenStack** foundation and the international OpenStack community, because Australia's flagship and internationally leading cloud for research utilises the OpenStack middleware.

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

The University endorses the IP position of digitisation, high-performance computing and e-Research as central components of future underpinning NRI. Additionally we observe that infrastructure is a complex matrix of people and services to be supported in an enduring manner. For example, the decommissioning at end of 2016 of the petaflop-scale supercomputer at the Victorian Life Sciences Computation Initiative (VLSCI), a non-NCRIS facility, funded 2010-2016 predominantly by the Victorian Government will remove around 10% of the peak computing resources currently available through the National Computational Merit Allocations Scheme.

While this loss of HPC capacity will have an immediate impact and the computational infrastructure will have to be sourced in other ways, it is extremely important to recognise that a substantial national-scale legacy of the VLSCI is the availability of a sizeable and highly skilled specialist informatics workforce that now underpins a wide variety of top tier computational life sciences research, including the NCRIS-supported EMBL-ABR capability. Without the stimulus of a major Victorian investment, this nationally important workforce would not otherwise have been developed over the past seven years.

As a further example of the critical role of human capital, the NCRIS-funded platform **AURIN**, an important NCRIS social sciences infrastructure investment, gathers different skilled professionals and expertise together; data analysts, technical experts, academics with periphery of people leading up to the core of operations. AURIN has been developed so that people can use it in the future without specialised skills to access the full swathe of the platform's capabilities, for example potential industry collaborators and government policy advisors. To achieve this end user flexibility, the infrastructure investment requires coverage for specialists with deep understanding of *discipline areas*, and also others specialists that work *across all NCRIS-funded projects with shareable skill sets*. This is a key emerging stratification of roles and expertise within the infrastructure space.

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?

Informatics is a capability that should be explicitly described as part of the NRI. Informatics infrastructure would address the following needs of: networking and funding local centres of expertise for the purposes of ensuring the development of technology; increasing knowledge transfer between research and informatics; establishing standards for storing and analysing data; making the necessary software tools freely available and standardising interfaces; development of long-term strategies for research, action, and funding, in order to improve the conditions for joint public private funding of collaborative projects; promote the sustainability of available data resources; optimisation of the use of computing capacities, in order to improve the utilisation of local resources through comprehensive resource mapping; contribute towards the improvements in the conditions for transferring data via cloud computing.

The human capital and associated protocols for agreeing on, and supporting the implementation of, national and international harmonisation of standards (including on metadata, citation details and consent records) should also be regarded as NRI.

With regard to the well-recognised need to better recognise the core input of **skilled people and workforces** in delivering Australia's NRIs, data infrastructure services and management demands a spectrum of expertise which is not currently available at sufficient scale. For instance: technical specialists that bridge between domains and data infrastructure to facilitate and enable the uptake and utilisation of the infrastructure and promote best practice; technically adept researchers and personnel who are deeply embedded in particular disciplines or topic areas; and research data curation and data operations roles.

The University also recommends greater recognition of the capability potential of **multi-disciplinary applications of humanities-social science data for medical research**. Such longitudinal data can also be utilised for epigenetic population health research, as it can be used also for the study of wealth creation, loss and transfer over generations, social mobility, geographical mobility, migration and its long-run effects and human interaction with the natural and cultivated environments.

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

The University observes that awareness and applicability of international opportunities is inconsistent across Australian research communities.

Examples where participation in large-scale global collaborations would benefit Australian research include: the **NIH Harmonised Cancer Datasets**; **Genomic Data Commons Data Portal** in the US; **DTL Dutch Techcentre for Life Sciences**; the **Digital Curation Centre** in the UK; the University of Umea, Sweden, where the Historical Database is being linked to the contemporary health data of Sweden; the Universite de Montreale where the Historical Register is linking to contemporary data, in particular to DNA samples; the **Historical Sample of the Netherlands** via the University of Amsterdam; the **History of Science Society** in the US, who are custodians of the key emerging resource for computational history and philosophy of science.

The University observes that part of the challenge with enabling participation in global research infrastructure is the impact of international data harmonisation standards. The infrastructure answer to this challenge may include the establishment of an overarching network, to hold citation and metadata about the sources of the data and operate as an ISO standardised and coordinated group.

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

The IP accurately highlights the increasing importance of facilitating access of NRI to international and industry partners, under appropriate conditions. The University adds that this needs to be implemented at the program level, as it is predominantly a policy barrier rather than technical one.

The University acknowledges that the principles of metadata, preservation, curation, provenance, and authentication, as expressed in the figure on Page 48 if the IP, are fundamental to the creation of a data infrastructure. However, the diagram does not adequately reflect that data used in research tends towards ad hoc and agile, nor that research infrastructure looks different to different communities, who engage with distinct skills sets, data standards, analysis engines, workflow approaches, and overall differing levels of maturity in their uptake of research ICT in research practice.

An evolution of the Figure would better capture the essential requirements of a transformed environment of a research data system suited to multiple research paradigms, widely varying research community maturities and complex dependencies on diverse aspects of data intensive research.

Appendix A

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