Submission

2016 National Research Infrastructure Roadmap Capability Issues Paper

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

The proposed list of capabilities is broadly appropriate.

The University of Sydney considers that there are interesting opportunities in structuring the fit between capability areas and the particular research facilities that would enable their advancement. There are opportunities for investment in research facilities that work across a number of these capability areas, as well as in more targeted facilities that are primarily concerned with one capability area. Both sorts of facilities are needed to ensure that these capability areas properly flourish and advance. This bi-modal approach to investment in national research infrastructure will enable the development of new methodologies that can be adapted between research communities, thus accelerating discovery and innovation. In this regard, we note that the success of a number of distributed national research facilities that operate as national capability grids (e.g. Horizon 2020's Global BioImaging is modelled on the AMMRF). This hard-won global positioning via NCRIS ought to be further leveraged, and has the potential to be a distinctive and successful feature of Australian national research facilities.

We strongly advocate the importance of the plurality of these capability areas. The way that we choose to respond to the most significant challenges of our time around climate, health, food, water, energy, communications, transport, manufacturing, construction, national security and producing stable economic and political systems, will largely define our future as a nation. In seeking to establish a national plan for research infrastructure, it must be consistently recognised that each of the identified capability areas has a key role to play. We would therefore urge against an approach that supports a very small number of "moonshot" projects because of the limitations that such an approach will impose on our broader national capacity for innovation. On the other hand, not funding new research infrastructure at all would be a reversion to a laissez-faire approach to research infrastructure. Non-strategic outcomes, the exclusion of smaller universities and poorly supported installations and facilities would almost certainly be the result.

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

In addition to the listed governance characteristics, we would recommend inclusion of a demonstrated capacity for:

- impartiality that is not biased towards particular disciplines or institutions; across the fields of both STEM and HASS;
- transparency;
- inclusiveness;
- achieving balance between the need for "top-down" processes, and user-driven "bottom-up" processes that drive the development of new capability in research facilities;
- fostering a culture of methodological innovation so that our national research facilities provide research communities with a capacity to achieve discipline leadership and innovation, and are not merely offering a "set-menu";
- long-term strategic commitment—important for lifecycle management of instrumentation, technical roadmapping and staff retention/refreshment
- agile responsiveness to fast-changing situations such as local, state or national emergencies, unexpected paradigm-changing scientific breakthroughs, changes to the global marketplace, or the rapid onset of unexpected economic circumstances.

More broadly, the University of Sydney notes that there is a missing governance element in the overall research infrastructure landscape. Whilst we recognise that different research facilities may need different governance models, ranging from incorporated through to unincorporated entities, there currently is no meta-structure at the program level to assess, evaluate or advise on the performance of facility governance and, when necessary, guide investment and dis-investment in particular areas. The University of Sydney is of the view that a serious commitment to national research infrastructure necessarily entails a serious commitment to national program governance. Moreover, our view is that national research infrastructure is a matter of national significance. The longstanding pattern of *ad-hoc* approaches to national research infrastructure planning is detrimental to the cause and ought to cease. Overall authority for national research infrastructure planning and implementation should be given to a properly established independent Commonwealth entity that is strategic, ongoing, consistent, and aligned to the national interest. It our view that no such organisation currently exists.

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

Yes, undoubtedly research infrastructure investment should include access to leading international facilities. In some circumstances, this ought also to facilitate Australian co-funding of multi-national research facilities. It is noteworthy that the successful Access to Major Research Facilities Program (AMRFP) formerly provided travel funding on a competitive basis for teams of up to three researchers to perform experiments at world-leading facilities such as telescopes, nuclear facilities, and X-ray synchrotrons to which they had been granted free access via an international peer-review system. The AMRFP delivered high scientific returns in areas as diverse as biology, chemistry, physics, astronomy, earth sciences, materials science and engineering, medicine and cultural heritage. This 'suitcase science' also served as an innovation platform: for example, solving the structure of the influenza virus by Australian researchers was the critical pre-cursor to the development the drug *Relenza* which was licensed to GlaxoSmithKline.

The decision to de-fund the AMRFP was unfortunate because there are numerous research infrastructure initiatives across the globe that Australian researchers should have access to so as to advance their research programs. The University of Sydney is of the view that a new Travel and Access Program (TAP) that covers both national and international facility access should be a key component of future research infrastructure investments. Operated by an independent peak authority for Australia's national research infrastructure, this program would enable Australians researchers from academia and industry to access the world's best research facilities across STEM and HASS disciplines, and would be structured to serve as a cost-effective solution to enable collaboration, discovery and innovation.

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

The University of Sydney anticipates such scenarios, including:

- where there is cutting-edge research expertise in Australia but the size of the research community is not large enough to justify expenditure in a local facility.
  This would likely include scenarios involving access to specialised capabilities in astronomy, space science, X-ray synchrotron radiation and neutron sources where Australia has considerable expertise but cannot feasibly cover all of the cutting-edge experimental capabilities available;
- where the cost of the research facilities is prohibitively high such that, regardless of the size of the Australian community, an overseas-based multi-national consortium approach to facilities predominates the field (e.g. CERN, or ITER).
- Instances where for geophysical, environment or other factors another country is better placed to locate such infrastructure (e.g. South Pole Telescope)

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

Yes, workforce skills are a central issue in research infrastructure planning. Moreover, workforce skills need to be addressed from a whole-of-career viewpoint so as to maximise the social, economic, scientific and technological impact of national research infrastructure. Issues around recruitment, training, retention and career progression for research facility staff are inter-dependent. It is our view that sophisticated, new generation research equipment is rarely used in an effective or efficient manner when dedicated technical specialists are unavailable to provide user-support and training. In essence, this issue is central to a national research infrastructure plan achieving the best possible outcome. Some progress in the fostering of this culture has already been achieved, and long-term funding stability will address further issues in this area.

For example, the Terrestrial Ecosystem Research Network (TERN) has catalysed the development of collaborative networks of skilled researchers, and these networks are now a key component of this research infrastructure. This is also true for the ANFF. An essential element of the National Imaging Facility (NIF) and one that has been identified in every survey of effectiveness of NCRIS, is the expertise offered through the Imaging Facility Fellows and Informatics Fellows. In addition to the value they add to the infrastructure at the institution/node level, they provide a mechanism for transfer of skills and technology across nodes and ensure training of the next generation of instrument scientists in a wide range of technologies. The Australian Microscopy & Microanalysis Research Facility (AMMRF) has pioneered programs for facility staff exchange and skills development, creating dynamic national cohorts of expertise. Our view is that these sorts of models for workforce skill development have been shown to be effective and are the foundation for future success.

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

We consider that national research infrastructure can facilitate training and skills development across different sections of the R&D landscape:

- **Industry:** a strong national research infrastructure landscape is essential for Australia's industrial prosperity as our economy broadens, evolves, and transitions towards one that is more advanced and innovation-based. Access to state-of-the-art research infrastructure for Australian industry, particularly start-up operations and SMEs, will facilitate skills development and necessarily be part of the transition process for our economy. Our view at The University of Sydney is that there are fledgling success stories in this area across the NCRIS portfolio, particularly in the AMMRF and ANFF, but that more could be done to facilitate this engagement across the broader research facility base.

- **Researchers:** a fundamental role of national research infrastructure is to create a research workforce that is trained and skilled so as to enable them to discover and harness new ideas. Several examples of this are already working well. In astronomy, the NCRIS-supported telescopes provide an effective and well-established opportunity for training and skills development for students and early career researchers. For instance, over one-third of Australian users of these facilities in 2014/15 were students. Such training and skills programs must continue to be supported under future national research infrastructure programs, especially as the more complex next-generation facilities become operational. National research infrastructure provides an ideal platform to underpin high quality postgraduate and postdoctoral research training and skills development. It achieves this through the quality of the physical infrastructure, the quality of the scientists supporting the infrastructure, and by facilitating national coordination through appropriate networking and governance. The AMMRF, ANFF, NIF, TERN and the NCI all have excellent companion narratives to this. These are the building blocks of a national innovation capability.
- **Research facility staff:** An excellent national cohort of research facility staff — that are highly skilled in facilitating the conversion of the enormous research potential of our national research infrastructure into outstanding research outcomes for the research user communities — must be a fundamental goal of this program.
- **Schools and the wider community:** Bearing in mind Australia's need to enhance our STEM capability in the decades ahead, as well as enhancing particular types of creative thinking across the HASS disciplines that engage with issues of complexity and problem solving around people and communities, we consider that outreach programs should be resourced as part of the national research infrastructure program. Our peak national research facilities can contribute significantly to interest in STEM and, more generally, enhance the quantitative competencies of our society.

We wish to highlight a particular opportunity and a particular challenge area in the training and skills area:

- The stunning success of the AMMRF's MyScope online training resource has resonated internationally. More broadly, we believe that Australia's national research facilities could be positioned to assume leadership in the development of online training tools, and that there may exist some opportunities to monetise these via point-of-use or sponsorship mechanisms.
- There exists a growing gap in the skills and training around the use of the available eResearch infrastructure in certain research communities, particularly in the arts, humanities and social sciences. This limits the extent to which researchers can exploit the available data and computing resources. More investment in discipline-focused initiatives would enable these research communities to better access the innovative tools and facilities needed to tackle with creativity the data-intensive projects and research challenges of the future.

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

We recognise that institutions have important responsibilities in this space. Just how these responsibilities are shared with national research infrastructure initiatives will depend on the funding models, governance structures, and policy nuances. We consider that a pressing issue for the sector is the development of career paths for specialist technical staff of research facilities. Predictable, long-term funding is essential for employment security and retention of these staff who fundamentally underpin our national research infrastructure. Uncertainty in operational funding remains a key risk for the success of many of our most prominent national research infrastructure initiatives. As the likely host organisation for many of these staff, it is clear that institutions must play a role in supporting and developing their careers. How this responsibility is shared more broadly is a key question. The fact remains that national research facilities that are hosted in research-intensive Universities contribute significantly to the national research training capacity.

We consider that there are particular opportunities and responsibilities for institutions to produce infrastructure-ready researchers. Institutions are uniquely positioned to provide a variety of initiatives to ensure the advanced utilisation of national research infrastructure. These could include the alignment of certain academic staff appointments, the establishment of specific research centres, and earmarking a quanta of research scholarships or fellowships with leading edge national research infrastructure.

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

We recommend that the following considerations be used to shape the access principles for national research infrastructure:

- major national infrastructure should serve the entire national research system and not only those institutions that are financially or geographically linked to a facility. Distributed, node-like organisational structures can contribute positively to this principle;
- transparency, clarity and flexibility in access policies is to be promoted;
- merit-based users ought to experience as few barriers as possible to access; and
- industry must be encouraged to access facilities. Practices should be initiated to provide visibility of the national research infrastructure to companies via engagement with industry associations and sector representative bodies, including industry growth centres.

We recognise that the question of user fees is inextricably linked to the question of access. There is now a substantial body of evidence which demonstrates that research facilities, of and by themselves, cannot be profit-generating operations (or even revenue neutral). They are a cost centre in the national innovation system and as such, access will necessarily require substantial subsidisation.Fee structures must be appropriately balanced so as to be high enough that researchers use these valuable facilities efficiently, but low enough so as to avoid overly restricting access and putting our innovation system at a competitive disadvantage relative to other economies who have higher levels of R&D investment. The above principles around transparency and flexibility need to be reflected in fee-charging models.

At the University of Sydney, we consider that special consideration should apply to the access and charging policies of national research facilities for industry-based users. We consider that much of the current practice seems to be overly simple: charge as high as possible to a rather limited industry customer base. A more sophisticated approach could be explored whereby a particular level of subsidised access to innovative start-ups and SMEs could be applied in order to encourage access by researchers based in resource-poor early stage companies.

It is reasonable that these various principles might not apply in the same manner under the scenarios of a national emergency, an unexpected paradigm-changing scientific breakthrough, or the rapid onset of unexpected economic circumstances.

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

In an era when the nature of research and innovation have never been changing more rapidly, it is understandable that certain facilities may become outdated. The processes summarised in the issues paper are reasonable and the need for appropriate timeframes around defunding/decommissioning is critical. We would draw particular attention to the risks around staff severance liabilities and consider that these must be properly planned for and resourced so that initial facility partner goodwill is not diminished. In addition to the challenges around the decommissioning of equipment, we also wish to add the need for proper technological and ethical processes around the disposal, archiving or opening up of the research data associated with defunded facilities.

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

We recommend the use of transparent, flexible models for co-investment that achieve proper financing of national research infrastructure. Financing of Australia's peak research facilities must be robust and comprehensive. The notion of a poorly-funded or under-supported national research facilities must be avoided and principles around what constitutes full-funding, business-as-usual funding and so on are important factors that need to be clearly articulated at the outset. The co-investment achieved in the NCRIS program has been a great success in many domains, and appears consistent with the principles set out in the issues paper. State governments, publicly-funded research agencies, universities and state governments are all examples of organisations that have contributed significantly to the existing national research infrastructure landscape. Processes to better synchronise this cycle of investment and the associated reporting by these organisations ought to be developed.

We consider that financial models have a seminal influence on the structure of facilities, and subsequent the development of research capability. For example, a key and successful feature of the Australian research infrastructure landscape is the leverage achieved from the patient capital of the federal government by that of partner organisations, resulting in a number of successful national 'grid'-style facilities such as the AMMRF, ANFF, NIF, IMOS and others. Ongoing investment from the federal government as the "foundation investor" provides the confidence for funding to flow from other stakeholders. The dis-benefit analysis here is telling: without federal government involvement, potential co-funders such as universities are likely to abandon national facility initiatives, leaving many Australian researchers without access to suitable research infrastructure, with a particular risk for non-partner institutions who may be reliant on the national capability. Moreover, competition between institutions will drive unnecessary duplication of infrastructure and result in diluted investments that fail to realise the full capacity of the technology and ultimately albeit indirectly create reduced value to the public purse. Viewed in this way, the leverage achieved from the foundational investment by the federal government in establishing and operating our distributed national research facilities is truly excellent.

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

Standards and accreditation requirement must be examined on a case-by-case basis. Whereas in some situations, users of research facilities must undertake entirely bespoke experiments, other situations may require standardisation. Where standardisation adds value to the research output, or broadens the potential community of users, including the potential for industrial users and/or commercial participation in some form, then it does certainly warrant consideration. It must be noted that accreditation or certification will require extra costs associated with the set up and maintenance of a quality management system.

The case of standards is particularly important in the area of data collection and publication, and especially in the context of credible delivery to users. Here, it must be recognised that national research facilities will play a key role in shaping the nature of data standards and the rise of the *hierarchical data format* is an example that is bringing research communities together and enabling collaboration that would otherwise be impossible.

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

There exists a substantial body of literature on the general rise in importance of national research facilities, and much material available on specific access policies for specific facilities. However, we propose that features salient to the Australian scene could be collated via a commissioned literature review on the management and governance of peak national research facilities. We would claim that the taxonomy of research facilities and the principles by which excellence is fostered in facilities of various size and scope is currently not available, and would be a worthy undertaking.

Undoubtedly, there likely remain aspects of best-practice that are in place overseas that have yet to be implemented in Australia. There are major pan-European, American and Asian initiatives variously in the areas of Precision Agriculture, Precision Medicine, Robotics, Big Data, Materials, and various Genome type initiatives, Environmental sensing, Space science, and more, that require careful study. Whilst we need to remain alert to the adoption of practice developed elsewhere, the particularities of the Australian research landscape and our national objectives need to be considered carefully before implementation. Moreover, examples of Australian research facility management that have been adopted overseas should be recognised as models for closer examination. The AMMRF have developed an excellent model for open access to national research infrastructure with a five-year rolling strategic plan for acquisition and distribution of newly developed high-end equipment in a national network of collaborative nodes. The EU Horizon 2020 initiatives EuroBioImaging and GlobalBioImaging (http://www.eurobioimaging.eu) openly acknowledged that they are based on the AMMRF model. Previous NCRIS investment in TERN has enabled Australia to become an internationally-recognised leader in terrestrial ecosystem observation. In the words of Prof David Schimel (NASA JPL, USA) “TERN is helping to bring about a paradigm shift in the way ecosystem science and management is done in Australia… The rest of the world is watching and hoping to learn.”

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?

We recognise the difficulty of these processes and point to the protocols that the CRC Program and the ARC have developed in relation to the shut-down arrangements for their centres.

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

It is unlikely that there is mechanism by which the capital investment and basic operational costs for national research facilities can be financed other than by targeted government initiatives. However, we do consider that there exists significant opportunity for enhanced coordination between NCRIS and related Commonwealth-funded schemes from the ARC, NHMRC, the CRC program, and others so as to maximise the benefits for all. This is particularly relevant to the model of financing facility operations. Models by which these agencies allocate credits to researchers that can be taken up in the nation's peak research facilities would be helpful, as would cross-promotion of these facilities to would-be applicants. Furthermore, success in national competitive grant schemes should be used as a measure of academic merit in the access policies of NCRIS and related facilities.

Health and Medical Sciences

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

Yes—cryo-electron microscopy is an essential inclusion in the discussion around emerging directions for biomedical research infrastructure. This technology is set to enable groundbreaking research discoveries in the health and medical sciences. Recent commentary in the journal *Nature* describes the impact of the new-generation cryo-electron microscopy as revolutionary[1], describing single particle cryo-tomography as the most significant development for structural biology since X-ray crystallography. *Nature Methods* identified it as 'technique of the year' in 2015. Recent hardware and software breakthroughs enable cryo-electron microscopy to now reveal the hidden machinery of the cell with unprecedented, near atomic resolution. This provides information about how molecules involved in disease might be targeted with strategically designed drugs. In the coming decade, researchers across Australia will require increasing access to these advanced techniques, which require not just "an instrument", but a number of machines supported by a national infrastructure ecosystem that provides end-to-end solutions across the cycle of these complex experiments that could span bio-banking through to advanced visualisation and bioinformatics.

We agree that new tracer developments for PET analysis and support for the development of better integration and standardization of facilities represents a significant gap for biomedical imaging. Imaging instrumentation is evolving rapidly and the limits of sensitivity and spatial resolution are paradigm changing. The capability to acquire whole body tracer kinetics at 40 times higher sensitivity (and 40x lower dose) than current PET technology will arrive within the next five years.

We are of the view that the emergence of compact light sources that enable the effective operation of a X-ray synchrotron in a laboratory is something that Australia must plan for. Using laser undulation of electrons so as to generate X-radiation that is intense and bright is enabling the generation of exquisitely detailed images of soft tissue at a cost and scale that makes clinical applications of synchrotron techniques practical. Improving our nation's health through better understanding of disease, more effective drug

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[1] E. Callaway, "The revolution will not be crystallized: a new method sweeps through structural biology", 525, 172-174 (2015).

development, and the enabling of clinical applications of emerging new techniques for biological imaging will have distinctly positive effects on Australia's health economics.

The academic and industrial opportunities arising from Australian organisations acting as genuinely fast-followers in new technologies such as whole body PET, and compact light source technology, where there might be relatively few such units worldwide, is very significant. Bearing in mind the large up-front costs (e.g. ~$20M), and the operational complexity, we consider that this sort of initiative requires a precinct-type approach where cross-disciplinary research excellence is matched with access to well-characterised patients, animal models and the full range of related translational imaging infrastructure and expertise. The strength of the precinct available via partnership between the University of Sydney, the NHMRC Clinical Trials Centre, ANSTO and the Royal Prince Alfred Hospital represents an exceptional opportunity to bring Australian biomedical imaging research capability to the very forefront and might represent a flagship initiative of the NIF.

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

We recommend participating in Global Bioimaging, an international network of collaborating infrastructures in biological and biomedical imaging for life scientists supported by the EU Horizon 2020 program. Its goal is to establish a sustainable network of international infrastructure partners to allow common access programs to their services and the exchange of best practice. Facilities will become interoperable with other international imaging infrastructures in their user services by standardisation and harmonisation of access protocols, methods, training programs as well as image data formats, analysis software and management. The AMMRF and the NIF are the founding partners of this initiative.

There is an opportunity for Australian researchers to be at the forefront of the next frontier of imaging technology developments by joining the EXPLORER consortium (http://explorer.ucdavis.edu). This US led consortium is developing a new generation of PET technology capable of simultaneously acquiring tracer kinetics from all tissues of the body at very low doses of ionizing radiation (<0.2 mSv). This technology will enable multi-disciplinary research teams to address major health challenges such as diabetes, mental illness and other complex multi-organ diseases which require a systems biological approach. Because of the low radiation dose, it will also open up PET research to new cohorts, such as pregnant women, children and prodromal subjects.

The University of Sydney also considers that it is essential to have a national facility such as ANZCTR (http://www.anzctr.org.au/) operating in Australia so that Australia contributes important data to the World Health Organisation's International Clinical Trials Registry Platform (WHO ICTRP) (http://www.who.int/ictrp/en/). ANZCTR is one of only 15 trial registries globally. Each of these government funded registries serves a particular geographical region and ensures the global coverage of the WHO ICTRP network of registries.

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?

Yes: health areas of interest such as vectors, pathogens, and aerobiology could be supported by investment in a range of environmental monitoring infrastructure. Given potential synergies in some areas, harmonisation of data infrastructure between the Capability Focus Areas of Health and Environment would be desirable. In the same way that vibrational spectroscopy is an area that is supra-critical to serve as a national platform such that the cost of not doing so exceeds the costs of operating a national facility network, we recommend the establishment of a national cell cytometry and mass spectrometry facilities as critical enablers of a precision medicine agenda. Moreover, our view is that a similar argument could be mounted in support of the NMR technique.

Over the next 10 years, Australia's national research infrastructure will play an important role in supporting the goals of the Medical Research Future Fund (MRFF). An important example is access to advanced imaging technologies, such as whole body PET, cryo-EM, and compact light sources that will enable MRFF-funded teams to evaluate their potential to improve health outcomes and lower costs through early diagnosis and intervention, as well as personalised and targeted therapies. There is solid evidence that such investments lead to significant healthcare savings in the long term. For example, when PET technology was first introduced to Australia in the 1990s it was considered an expensive technology. However, it was subsequently shown to significantly reduce the overall cost of cancer care while improving patient outcomes by (a) detecting distant disease and, thus, avoiding costly surgery for patients who ultimately receive no benefit and (b) switching patients from ineffective drugs early in the course of treatment to more effective drugs (Buck et al, Journal of Nuclear Medicine Technology, 51(3): 401-412, 2010). We anticipate similar economic gains in relation to complex multi-organ diseases, such as diabetes and mental illness, that represent a significant drain on the economy due to disability and loss of earning potential. Strategic investments in national infrastructure and the MRFF will provide answers to these important questions and deliver long-term savings in the healthcare system and the broader economy. From the viewpoint of national health economics, we might ask whether we can afford not to invest in frontier technologies such as advanced PET and cryo-EM within the next several years.

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?

We consider that there are critical gaps in the current NCRIS investment, and that these gaps were reflected in the Issues paper. Each represents a significant scientific and economic opportunity.

- **Space Research and its Earth Applications:** we advocate for the development of a research capability for building flexible, long-term, sustainable, near-Earth Cubesats, operating in low altitude (300–1000 km) multi-generation constellations with leading-edge sensor-web, networked capabilities in EOS/GPS, space technology, space situational awareness (SSA) and space weather. We suggest that investment in this capability may well feature as a critical step in the nucleation of a successful Australian space industry.
- **Digital Agriculture:** we advocate for the development of a research capability that is focussed on capturing, sharing and connecting researchers with data for increasing agricultural productivity and incentivising farmers to share data with national infrastructure providers. This will primarily include data on soils, food and feed crops, and their genetics, yields, spatial and temporal coverage of crops in the landscape, and water availability and use. We suggest that this could be built on NCI and eResearch hardware. The social and economic impact of such a capability would likely be very high.
- **Data Translation or Knowledge as a Service (KaaS):** we advocate for the establishment of a new capability that is focussed on the application of modern machine learning and data science tools to enable the transformation of data into discovery in Australia's national research facilities. This capability would enable scientists to connect with all Australian and international data, and to develop exploration and discovery applications.

Finally, we note that tools for high precision isotopic analysis of minerals have evolved significantly in recent years and are essential to understanding the mineralisation processes that drive Australia's resources industry. As an example, our geologists require access to new-generation secondary ion mass spectroscopy (SIMS) to remain competitive and relevant in their field. In particular, the use of new ion sources with an order-of-magnitude increase in brightness promise massive improvements in lateral resolution with no decrease in sensitivity. This will be of particular use for dating zircons by analysis of oxygen isotopes and for measuring sulphur isotopes in sulphide minerals. Both of these are key to developing our understanding of the geophysical processes that underpin innovation and development in the resources industry. For example, these improvements will bring improved efficiencies in mineral exploration locally and globally. It will also contribute to work in nuclear safeguarding with the International Atomic Energy Agency (IAEA).

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

We consider that delivering Australian researchers continued and persistent access to data and services is key to ensuring we have access to the information to make the next big discoveries. Australian researchers have good collaborative links with international space agencies (NASA, ESA, JAXA), weather and climate groups and agricultural research agencies including the UN and US FAO on food security. A structured framework for these relationships is urgently needed. More specifically, we recommend engagement with the following international projects:

1. The Global Soil Map project (http://www.globalsoilmap.net/) is working on projects to extend the current mapping strategy down to higher resolutions; the current international target is 30m. Coupling the soil algorithms with remote sensing such as Landsat and Sentinel.
2. ARC ITTC Food Safety in Fresh Produce has a number of projects looking at the relationship between challenges faced by our food industry and climate, transport and safety concerns.
3. The European Unions Horizon 2020 programme will spawn a number for projects such as “Food watch from space”, “Monitoring Soil Moisture for Optimised Irrigation”, “Sustainable Forestry Management” and more. http://www.copernicus.eu/main/agriculture-forestry-and-fisheries
4. POLARIS: A 30-meter probabilistic soil series. (University of Nebraska, Princeton, The University of Sydney, USA National Soil Survey Center).

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?

We concur with the issues paper that there are gaps in our national coverage of Australian ecosystems, and propose that these are wider than the three identified areas (arid, alpine, tropical). We consider that there is a need for an overarching meta-structure in this space, that provides strategic oversight of and enables collaboration between developments in the terrestrial, coastal, underwater, atmospheric and space environments. We recognise the distinct value, methodologies and communities that these capabilities represent and urge against a simple aggregation. There is a need for greater coordination across these capabilities. We suggest that this could be done via a strategic governance council that coordinates funding and targets for groups such as IMOS, TERN, AusScope and parts of BioPlatforms Australia.

We also wish to point out that Australia's 5.9 million km^2 Antarctic Territory is approximately similar in area to mainland Australia (minus Queensland) and is of increasing strategic importance to our nation. Its terrestrial ecosystems, and how they are changing over time, represent a sizeable gap – and opportunity –

in Australia's current and future environment and natural resource management capability. Australian space science and technology would likely be one of a number of opportunities that this prioritisation would open up.

Finally, we are concerned that there is considerable unrecognised scope within the Environment & Natural Resource Management capability focus area for the creation of jobs and economic growth. Examples include the development of an Australian space program and a space industry, superior performance of the agriculture sector, and informatics-related industries, all of which could drive new job creation.

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?

Atomic scale microscopy is an essential technology for materials, nanotechnology, engineering and chemical research. As we endeavour increasingly to "engineer" materials at the atomic scale, materials design increasingly requires knowing precisely which atoms are where, and how they are bonded. Recent breakthroughs in the technology for aberration-correction electron microscopes and atom probe tomography are beginning to yield atomic-scale structure-function relationships. An increasingly broad range of researchers across the country will depend on access to atomic scale microscopy technology in the decade ahead. For Australian research and development to be competitive, this will require not only resourcing this expensive and complex instrumentation, but also the associated technical support, sample preparation and informatics resources that are essential for effective workflows. At stake is our capacity to develop and manufacture new high-value materials for industries ranging from electronics, photonics, space technology, chemical processing, metallurgical processing and mining. High-end aberration corrected electron microscopes and atom probes are expensive, and require a great deal of supporting infrastructure. It is impractical for institutions to replicate them. As described above for cryo-electron microscopy, the AMMRF have developed a plan to host a national atomic-scale microscopy capability consisting of a grid of strategically-located high-end open-access facilities supported by mid-range instruments in a wider range of locations. The University of Sydney endorses this approach.

We consider that vibrational spectroscopy is now a highly advanced characterisation technique that would serve the national interest better if structured as a nationally coordinated platform. Advances in vibrational spectroscopy are such that there are now extensive user-communities that span across the fields of medicine, agriculture, mining, museums, art galleries, advanced manufacturing and the pharmaceutical industry. A national research facility in vibrational spectroscopy would effectively drive innovation in the area. This is a field wherein there is rapid methodological innovation and technology advancements, and the multi-million dollar high-end instruments required by Australian researchers are at risk of being difficult or impossible to attain and support in a national strategic framework. The University of Sydney advocates the establishment of a new national platform in this area and argues that the primary driver for this is the capacity for this national community to better contribute to an innovation agenda via coordination.

At the other end of the scales of time and space, the issues paper correctly identifies the major emerging capability needs for astronomy. We note that Australia's ability to play a leading role in these major global infrastructure projects is built on human capacity and capability, and our international reputation in key areas of astronomical science and instrumentation. It should also be emphasised that to extract maximum return on investment in the capabilities listed, there must be considerable cross-utilisation of the instruments by the astronomical community.

The lack of partnership in an 8-metre optical telescope is an urgent and critical gap in the Australian astronomy portfolio. Partnership is necessary for Australia to maintain the required expertise, science foundation and technical capacity to capitalise on Australia's significant investment in GMT, and to continue Australia's leadership in instrumentation development. Astronomy Australia Limited is actively exploring partnership opportunities with major optical observatories such as the Japanese Subaru telescope. Their scientific and instrumentation directions are closely aligned with those of Australian astronomy, and they may benefit from Australian expertise in cutting-edge adaptive optics systems and multi-fibre spectrographs with robotic fibre positioning systems. It is important to note that multi-wavelength astronomy is where the greatest scientific gains are made, so that researchers need to use both radio and optical telescopes. Cross-fertilisation of ideas for instrumentation and eResearch capability is critically important and benefits the training programs of students and early-career researchers.

The University of Sydney has demonstrated a major commitment to Australia's nanofabrication capability. Our $130M *Sydney Nanoscience Hub* hosts over 700 m^2 of ISO 5 and ISO 7 cleanroom space. Although a relatively minor partner in ANFF to date, Sydney is keen to assume a proper leadership role in the burgeoning area of nanofabrication and our contribution of this outstanding resource into the national mix of capability operated by the ANFF network is highly significant. In this regard, we endorse the ANFF submission and anticipate significant impact will follow from the recent announcement of two new ARC Centres of Excellence, EQuS and CQC2T, totaling $65M for the next 7 years, as well as multi-million dollar research engagements with Microsoft, Intel and other major corporations.

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

All of the major astronomy infrastructure projects over the next decade are international in scope. For major global projects like GMT and SKA, Australia has already made significant investment and we should continue to position Australia to play a leading role in the science and technology for those projects. There are also opportunities to leverage Australian expertise and innovation in order to join collaboration in other global facilities, such as space missions and high-energy instruments.

The issues paper also correctly identifies the international Laser Interferometer Gravitational Wave Observatory (LIGO) project as a new area of astronomy that is poised to make breakthroughs in our understanding of the extreme physics of black holes and warped space-time, and will inspire the next generation of Australian scientists and engineers. We note that Australia could host a southern hemisphere-based detector, which would work with the northern-hemisphere-based detectors to help localise the origin of the gravitational waves with much greater precision.

The National Nanotechnology Infrastructure Network (NNIN) in the USA is an integrated partnership of fourteen user facilities, supported by the NSF, providing excellent capabilities for nanoscience and nanotechnology research. There are links to this and kindred facilities in Europe and Asia with the ANFF and these must be maintained as a vital strategic element of the Australian capability.

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 ~ 2009, the federal department responsible for NCRIS initiated a national characterisation council that brought together leaders from the AMMRF, NIF, the Australian Synchrotron and ANSTOs neutron scattering facility. Councils such as this, which have an explicitly scientific (rather than governance or management) agenda, can have excellent impact for their substantial user communities. Similar councils could be envisaged to bring together ANFF, BioPlatforms Australia, Biofuels and other organisations with professional synthesis and/or fabrication capability and across other domains such as eResearch, and environmental sensing and modelling.

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?

We are concerned that there is insufficient recognition of the challenges and opportunities for advanced computational approaches to answer questions in the humanities and social sciences. Bayesian methods, natural language processing, automated image analysis, and machine learning, for example, are emerging as key tools that enable hypothesis testing, quantification, analysis and synthesis in these disciplines in a manner that is truly transformative. Research facilities that service these communities must include a people-based infrastructure that can bridge the discipline frontiers with the opportunities that arise from high-performance computing, new types of data, and methodological advances. Access to high quality data services for national social security, health and population data is critical to these domains being successful and innovative. Humanities researchers supported by the right tools, skilled technicians and data have the opportunity to increase engagement with community and industry partners. It is critical that these resources are heavily embedded within the disciplines themselves in order to enable the pollination of new ideas and to help those research groups evolve in rapid and novel ways. A strictly "service" style provision is unlikely to effect broad scale change in these types of disciplines.

More generally, we agree with the broad thrust of the emerging directions described. We suggest that there are opportunities for cross-cutting interactions between various national research facilities in the space of conservation where analysis, imaging or computation all variously serve as enablers.

We agree with the emphasis on digitisation, but are concerned that the requirements around resourcing for this have not been fully considered. For example, the workflow in creating 3D digital image via (e.g.) X-ray microtomography of a valuable, fragile object that can subsequently be 3D printed, displayed and studied further, either as a solid object or as an online digital dataset, involves a complex workflow, ethical challenges, and major data curation and warehousing issues. Moreover, the long-term (5+ years) financial impact of digital objects needs careful consideration - an issue that was poorly addressed by previous NCRIS models. The University of Sydney has large, culturally-significant physical data collections, some of which are over 150 years old. A broad-based national infrastructure capability dedicated to their digitisation would greatly enable access and reuse. However, digitisation is a highly specialised task and the University would recommend that resources are focused around some particular strengths (e.g. Audio and Film) than across the full spectrum of analogue data sources. Prioritisation of which assets should be digitised should be driven by existing national research agendas and collections of national significance, not on a novel ranking strategy, combined with acknowledgement of format obsolescence and physical fragility of the carrier medium.

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 national capacity for quantitative methodologies in the arts, humanities and social science is in a nascent state. This is in part linked to the lack of investment in facilities for this area in the recent past. In recognition of this, and the fact that an effective research infrastructure in this area offers the potential for major social and economic impact, we recommend that a people-focussed infrastructure is needed as a key priority. Links between engineers, computer scientists, mathematicians and researchers in the arts, humanities and social sciences are essential to facilitate the next wave of advances in these fields. The depth, breadth and quality of culture and community researchers using digital methods is significantly greater in the US and EU, and as an investment in people-based infrastructure, formal links with leading international digital humanities programs like CLARIN (www.clarin.eu) and Digital Humanities Summer Institute could be established and maintained through a Travel and Access Program (TAP).

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 previous infrastructure roadmaps were more comprehensive in their coverage of these disciplines, and this issues paper was not sufficiently balanced in terms of disciplines. The humanities and social sciences are at the heart of the University of Sydney's research and educational vision and they should be for Australia too, where interdisciplinary solutions can be applied to help solve contemporary challenges such as climate change, resource management, health and welfare. Access to supporting infrastructure is critical to enabling these outcomes. Despite this, it is clear that the Understanding Cultures and Communities capability did not greatly benefit from the previous roadmaps in any long term or sustained fashion. The University of Sydney recommends that the frameworks and delivery mechanisms deployed through this exercise aim to empower these disciplines to own and drive outcomes that are aligned with their research questions and agenda, while at the same time investing in skills, methods and infrastructure that has the power to transform and create a culture of innovation. For example, following the leads of reports such as Turner and Brass "Mapping the Humanities, Arts and Social Sciences in Australia" (2014) would empower any investment in these domains.

National Security

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

The issues paper addresses the key issues in this space. The diversity of requirements for national security is a challenge that will require careful analysis. We consider that national security represents an opportunity for the integration of cross-cutting capabilities from across the national research infrastructure. This is because it is apparent that many national research facilities can contribute to national security. Therefore, a high level inter-facility coordination that preserves a certain level of effort and capability devoted to national security is worth considering.

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

The Department of Homeland Security in the USA is an example of a high-level organisation that coordinates federal and state resources, including a wide range of research facility resources, for a common purpose.

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

The capability "Space research and its Earth applications" proposed earlier provides important scientific and economic opportunities that are also relevant in this domain. The effects of solar and interplanetary disturbances on the Earth's magnetosphere – ionosphere – atmosphere – ground /ocean system, and on human technology remain to be properly understood and harnessed. SSA and space weather data / predictions are increasingly vital for safeguarding Australia's national security, the international economy, and critical infrastructure such as electricity power grids and communications. For instance, a capacity to predict the arrival, nature, and consequences of events such as the pre-Space Age "Carrington Event" in 1859 in sufficient time to take mitigation measures is clearly crucial for Australia.

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?

We are concerned that vast amounts of data are being generated across NCRIS capabilities, and yet there are currently no secure long-term storage options available that also permit ready access for the wider research community. Additional capabilities not currently identified in the Issues Paper include public cloud infrastructure and practical data management capabilities. This challenge needs to be urgently addressed to protect the existing investment in NCRIS, preserve that legacy and set out a plan for the future of our research data.

Peak computational facilities provide access to specialised resources that are by design cutting edge, high value and drive research outcomes. A focus of resources on well-defined capabilities like High Performance Computing allows for expertise and competitive advantages to be built and maintained. The University of Sydney strongly supports the continued investment in the National Computational Infrastructure and recommends that national research infrastructure funds be regularly prioritised and committed to keeping the facility globally competitive (i.e. Top 25) on a regular basis. Furthermore, eResearch capabilities need to align and be user driven rather than technology driven. For example, rather than eResearch funding small, and rapid infrastructure development projects, the underpinning research infrastructure should work with other NCRIS data capabilities (e.g. IMOS, TERN and AuScope and others) to deliver long-term roadmaps whereby investment is aligned with needs. There is a persistent misconception that data alone is the key to the puzzle. This outdated position underplays the nexus of data and advanced computational methods and drives suboptimal outcomes and capabilities. Above all, infrastructure needs to dovetail with all of the community, and not be driven by fractional or factional needs.

In addition to peak computational facilities, the national funding schemes ought to assume particular responsibility for networking and identity management. The ten-year trend horizon for research and scientific computing is opaque and pre-determining it through large capital investment in commodity technologies that quickly become obsolete will not provide the Australian research community with the flexibility and agility required to adopt innovative and disrupting technology. eResearch services need to be provided at significantly below market cost, or free of charge, and be based on user demand and transparent co-investment. For example, a national eResearch help desk service across all NCRIS capabilities is needed to provide support back to capabilities on issues such as networking, security, data integrity and access. It is highly advantageous for the infrastructure to be able to respond to evolving technology developments and user needs in a timely fashion.

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

There are a number of international programs we can engage in and learn from including:

- InCommon - https://www.incommon.org/
- OpenAire - https://www.openaire.eu/
- EuDAT - https://www.eudat.eu/
- XSEDE - https://www.xsede.org

We also recommend working with the leading international data-intensive projects to design and build the next generation of ICT infrastructure. For example, Astronomy research has requirements that will rapidly increase in the next decade, as new telescopes generating unprecedented data volumes and requiring significant HPC time for data processing and modelling. In particular, the Square Kilometre Array (SKA) Phase 1 will produce 100s of petabytes of data per year for transport and processing. Projects like these with enormous HPC and networking demands (e.g. near exascale computing for dedicated processing and ~1 Tbps network links) that must be carefully planned well in advance, but also provide Australia with an opportunity to invest in the skills and technology to support a range of disciplines and capabilities.

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 of Sydney, like many other institutions and facilities nationally, did not observe a satisfactory level of short or long term value from the very large capital investments in the previous eResearch schemes. We have also been dismayed to find problematic financial burdens from RDSI and NeCTAR creep into our operations without any sense of prioritisation, research alignment or long-term planning. The use of “nodes” diluted and distracted the delivery of outcomes, and was principally not aligned with investments in research in either competitive funding or industry partnerships. The state-based nodes have repeatedly been inefficient and problematic in terms of longevity and sustainability. They neither provide peak capabilities that can be globally competitive, nor can they be customised enough to work seamlessly in the local context. In the future, we recommend that investment in underpinning research be made directly to the specific research facilities, or institutions (Tier 2) that are primarily responsible for the operations and delivery of a service. Where appropriate, the investment may be needed at the singular peak national facilities (Tier 1). We would urge that this contemporary integrative approach is superior. We do not see a future for a middle Tier 1.5.

Finally, we note that robust access and authentication services are required, which will work for all the services available in the eResearch infrastructure. Access and authentication should work seamlessly using institutional authentication. This would also enable machine-to-machine access to data and services.

Data for Research and Discoverability

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

The data infrastructure, e.g. ICT technologies like compute and storage, landscape is rapidly shifting to a consumption or service approach. The funding models must ensure the research community has steady and predictable access to the resources they need to effectively carry out their tasks. A capital-only ICT investment strategy is short-sighted and works against industry trends. The University of Sydney recommends that any National Research Infrastructure ICT body has the discretion to update its funding mechanisms to match best practice investment. The future of innovation in Australia will not come from building large monolithic and disjointed ICT ventures. In addition to the points outlined in the issues paper, we recommend that in the future, the infrastructure should be more flexible and scalable, in particular focusing on how best to coordinate to achieve a truly national approach. Policy and infrastructure should support the archiving and preservation of all research datasets, including sensitive datasets, from across all domains.

Innovation and longevity will come from a highly skilled support workforce — architects, data engineers, solution designers — working in close collaboration with their academic and industry peers. This workforce can adapt to market changes quickly and ensure that each domain is investing in a just-in-time basis, and in platforms that are built with their discipline needs at the forefront of design. This workforce should be supplied with tools that reduce the time to research outcomes, specifically tools to transfer data, upload data, migrate data, replication services, high availability data services, and environments to enable reproducible science.

Most NCRIS capabilities are producing ever larger data files due to the increasing richness of data obtained from contemporary techniques, e.g. the increased digital and spectral resolution of modern detectors, and the transition from probing systems in two- or three- dimensions toward the routine acquisition of 4D and 5D data arrays where compositional and time-resolved information are superimposed onto spatially resolved data sets. In addition, they are increasingly generating internationally significant data, warranting sharing and re-use. In response many facilities, such as the AMMRF, are developing plans for a national approach to data management. Success will require infrastructure to support data acquisition and high-speed data transfer, secure storage that allows sharing in a controlled way (through authentication and registration) and the capacity to undertake cloud-based data analysis on stored data. Most importantly, successfully achieving a national data solution requires capability-based data and informatics engineers to implement solutions and to provide expert advice and support to facility users. The University of Sydney would recommend these requirements be incorporated into any new capabilities for Data for Research and Discoverability.

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

Yes: key international programs include:

• EuDA https://www.eudat.eu/ • Horizon 2020 https://ec.europa.eu/programmes/horizon2020/
• Helix Nebula http://www.helix-nebula.eu/ • Apache Airavata https://airavata.apache.org/
• European Open Science Cloud http://ec.europa.eu/research/openscience/index.cfm?pg=open-science-cloud

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 Data for Research and Discoverability capability needs to have increased emphasis on methods and "data science". Fundamentally, the world is already on track to manage massive data holdings, with commercial providers like Amazon providing far greater capabilities than any of the legacy NCRIS data platforms. We recommend an approach that invests in a) institution-based informaticians who have highly developed data techniques and methods, an enabler that will drive new scientific outcomes in discipline and multi-discipline research; b) providing direct "data" investment into other successful Research Capabilities to increase their ROI and cutting out the middlemen so that ICT/data is not mediated by third parties (e.g. RDS/RDSI), which to date have demonstrated gross inefficiencies and; c) investing in data and knowledge services over infrastructure.

Data and cyber security is an area that will require a vast increase in resources and skills in order to meet challenges from local and international threats and risks. The increasing use of born-digital sensitive data in research can only be harnessed if there are systems and processes in place that the very basic level protect data contributors and researchers. While data sharing is important, fundamental research in medical, defence, and commercially- and culturally-sensitive domains (which prohibit data sharing) can offer outstanding community outcomes. Too strong a focus on Open Data will potentially jeopardise nationally significant research agendas. Investment in core data skills around encryption and data linkage, coupled with access to contemporary ICT services, will provide a RoI based on new techniques and the deployment of existing methods in novel domains. The University of Sydney is a leader in this space with the establishment of the Sydney Informatics Hub and the Centre for Translational Data Science. Our substantial investment positions the University to actively lead any national push for data security as an underpinning capability and feed into the National Security capability.

The roadmap must re-engineer the current national governance and operating structures of the existing infrastructure in this space in order to enable decommissioning and commissioning in a flexible and effective manner. Each of the infrastructures should work closely to provide an integrated service to deliver a serious impact at a global level. Easy access of cloud infrastructure to international collaborators should also be considered.

Other comments

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

We would draw attention to the potential for Australia to leverage from our national research infrastructure investments in a way that facilitates the development of an industry sector devoted to scientific instrument-development and manufacture. The national capability in the general area of methodology and technique development is excellent both in terms of software development, eResearch capacity and instrument adaptation, and development. A mechanism to capture the benefits of these innovations and the promotion of a new industry sector that specialises in detectors, emission sources, lenses, through to visualisation, analysis workbenches, metadata aggregation and informatics is worth careful consideration.