Submission on the 2016 National Research Infrastructure Roadmap Capability Issues Paper

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1 Background Comments

The *Science Statement for Western Australia – Growing Western Australia*, launched in April 2015, identified the following as the Western Australian (WA) State Government's five science priority areas:

- mining and energy;
- medicine and health;
- agriculture and food;
- biodiversity and marine science; and
- radio astronomy.

The Science Statement also identified the following areas of opportunity that cut across all five of the science priority areas:

- data intensive science;
- water science;
- science, technology, engineering and mathematics (STEM) education and engagement; and
- collaboration at a state, national and international level.

This submission predominantly focuses on national research infrastructure needs explored in the Issues Paper that best align with the WA State Government's science priority areas and areas of opportunity, and how WA could lead or significantly contribute to current, emerging and new capabilities identified in the Issues Paper.

The submission was developed in collaboration with, and has the strong support of, WA's Chief Scientist Professor Peter Klinken.

2 National Research Infrastructure Policy Issues

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

Consideration of whether any other capability focus areas (or capabilities within these areas) should be explored should assess alignment of the Issues Paper with the Australian Government's set of Science and Research Priorities and corresponding Practical Research Challenges, and the Australian Government's Industry Growth Centres. For example, should there be a separate capability focus area for food or advanced manufacturing (including capabilities such as 3D printing and systems on a chip)? Consideration should also be given to the industry or other end-user endgame associated with capability focus areas (and capabilities within these areas), e.g. Austrade's global trade themes for different Australian industries or sustainable management of estuaries at a continental scale.

Additional capability focus area – Research Translation Infrastructure:

There is a need for national open-access infrastructure to support science and technology translation and development across a wide range of sectors in Australia. The nature of such infrastructure would vary according to the needs of different sectors. This infrastructure could include a national network of pilot-scale facilities to support Industry Growth Centres with each facility specialising in a different area of need, for example a pilot plant facility in WA to support the liquefied natural gas sector and a pilot plant facility in Queensland to support the mining equipment, technology and services sector (including technologies to improve mineral extraction).

Research translation infrastructure in the health and medical science area could include a national network of clinical trial facilities and also infrastructure for development of scalable production processes for biologics and other novel therapies. Potential examples in other sectors include infrastructure for development and testing of advanced materials, objects or devices, and for development and testing of cyber security products, and pilot facilities for testing the utility of platforms and sensors for marine monitoring.

While some of the seven current capability focus areas in the Issues Paper have addressed translation, its importance warrants inclusion as a separate capability focus area.

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

There is a need for open and transparent frameworks for co-investment in national research infrastructure, particularly for expectations regarding co-investment by Australian state and territory governments.

In relation to data linkage infrastructure, there may be other factors to consider for optimal governance, such as collaboration around ensuring a single point of truth (storage of every data element only once, with linkages by reference back to the primary location) for the use of data linkage for research outcomes in the areas of health (including mental health), social services, corrective services and child protection. In addition, consistent frameworks for access to confidential information relating to an individual are necessary, with alignment of Commonwealth and State privacy legislation.

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

Yes, where relevant.

Example – Metabolomics:

Investment in metabolomics as part of national ‘omics research infrastructure would assist in maximising Australia’s opportunity to become a member of the International Phenome Centre Network, which is led by the UK’s National Phenome Centre.

The International Phenome Centre Network focuses on large-scale human metabolic phenotyping (profiling) of patient and epidemiological study samples that will benefit translational medicine for prevention and treatment. Membership of this network would provide Australia with access to a world-class capability in an important emerging and evolving field of research with standardised, best-practice methods, and international collaborations.

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

Access to international facilities should be prioritised over developing national facilities in instances where development of national facilities would require substantial capital investment and such facilities may then be superseded by next generation facilities internationally.

Example – Gravitational wave detectors:

It can be argued that it is not worth Australia investing in second-generation gravitational wave detectors (e.g. the advanced Laser Interferometer Gravitational Wave Observatory (LIGO) observatory, USA) when third-generation detectors are on the drawing board that would allow for precise astronomical studies of gravitational wave sources.

Instead, it would be better to enable Australia to join second-generation gravitational wave detectors (operational, under construction or planned, e.g. LIGO India which is expected to be functional by 2023). However, in the event of the offer of substantial co-investment by another country or countries towards an Australian gravitational wave detector, this stance could be reconsidered.

It is also important to note that Australia has already made a major commitment to a mega astronomy infrastructure project in the form of the Square Kilometre Array project.

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

Yes, as without the technical skills required to operate/maintain the research infrastructure, the capability of the infrastructure becomes null and void. Investing in education and training to achieve a highly educated research workforce that matches the needs of current and future research infrastructure, and current and future industry needs, will translate to economic success and future prosperity.

Training of PhD students and early career researchers is important to maximise use of research infrastructure as these researchers develop their careers, and could contribute to a pool of skilled staff to support research infrastructure. This training can also have advantages for those researchers (and their employers) whose career path leads into industry.

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

Having cutting-edge facilities and equipment requires highly technical skills in the people who operate the equipment. Ensuring that research infrastructure is world-leading will in turn help facilitate enhancing the training and skills required of the research workforce. Training courses, student internships and assistance with using research infrastructure for research projects (including PhD projects) would assist in skills development.

National research infrastructure could also undertake STEM engagement with high school teachers and students to contribute to the early stages of development of the researcher/technical talent pipeline for Australian science, including for research infrastructure.

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

Research institutions should have a high level of responsibility and interest in developing the researcher/technical talent pipeline relevant to the infrastructure in place, with reasons including because this will contribute to their research efforts.

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

Principles that underpin access to national research infrastructure should include the following:

- Access should be as equitable as possible, but merit based (with priority given to research in the national interest), and on a competitive merit basis if insufficient time and resources are available for access by all interested users;
- Projects can involve researchers and/or end-users of research such as industry.
- Projects must be research- or research translation-focused;
- Project proposals must present an impact statement (including benefits for end-users where applicable) and a summary of the pathway to impact;
- Project proposals must demonstrate research significance, practical application and benefits to Australia;
- An online, publicly available registry of current and past projects should be maintained; and
- Projects (if not confidential) should commit to communicating outcomes of using research infrastructure, e.g. through publication of case studies.

3 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?

Identified emerging directions and research infrastructure capabilities:

5.1.1 Big health data; 5.2.3 ‘Omics; 5.2.4 Biobanking & population genomics; 5.2.5 National health & medical data capability; 5.3.5 Managing & leveraging research data insights

Data linkage:

The Office of Science agrees with the views articulated in the Issues Paper that new opportunities would be created by linking ‘omics data and linking health and non-health data sets, and considers that the suggested national networked approach could be achieved through the Population Health Research Network (PHRN).

PHRN has building a nationwide data linkage infrastructure capable of securely and safely managing health and health-related data from around Australia to improve health and related research, whilst minimising privacy risks associated with use of personal data.

PHRN is a national network coordinated by the Program Office located in WA, and comprising a network of Project Participants and data linkage units located in each Australian state/territory, including the Centre for Data Linkage at Curtin University (WA) and the WA Department of Health's Data Linkage Branch.

A significant expansion of Australia's data linkage infrastructure will be required over the next ten years to meet researcher demand for access to high quality linked data at the person level across the spectrum of health and human research in Australia, from 'omics to clinical trials to health, medical and broader human services research.

PHRN has built on the success of well-established data linkage units in WA and NSW/ACT. WA has been a world leader in data linkage for many decades, and is internationally known for the breadth and depth of the datasets collected through longitudinal population-level health studies such as the Busselton Health Study and the Raine Study.

The WA Chief Scientist is currently leading a review aimed at enhancing data linkage in WA (including whole-of-government data linkage) to be able to meet the growing demand and increasing scope of data linkage beyond the health sector to include a range of other social, economic and environmental areas. The review's remit includes consideration of barriers to data linkage, processes and governance, and current and future requirements for data linkage in WA. The outputs of the review should also inform data linkage at the national level.

<u>Metabolomics and biobanking:</u>

Metabolomics is the measurement and analysis of metabolites (small molecules that are the intermediates and products of cellular processes) in biological materials such as blood, urine, saliva, and tissue/plant/microbial extracts.

While lagging behind the application of genomics to precision or personalised medicine, large-scale metabolic profiling in human health and disease is an emerging and growing field that holds considerable promise, including for development of diagnostic and prognostic indicators (biomarkers), identification of drug efficacy and safety and other responses to treatments, and monitoring patient journeys in hospital environments to improve patient care.

Australia has the opportunity to make a significant contribution to realising the promise of the application of metabolomics in precision medicine by building on existing capabilities within Bioplatforms Australia, including in WA through the WA Health Translation Network (WAHTN) and WA Bi-omics Facility, the first integrated 'omics (genomics, proteomics, metabolomics and bioinformatics) facility in Australia.

WA has strengths in metabolomics, e.g. infrastructure, collaboration within WA through the WAHTN, internationally recognised metabolomics researchers and international linkages, including with the UK's National Phenome Centre and the Singapore Phenome Centre. This has led to the opportunity to join the International Phenome Centre Network which focuses on human metabolomics. Membership of this network will be limited to 12 centres initially to achieve the desired harmonisation of methods globally and implement best practise protocols. The members thus far are network-leader the National Phenome Centre (UK), a phenome centre in Birmingham (UK) and the Singapore Phenome Centre, with centres in Japan, China, Taiwan, Canada and the USA at the planning stage.

The linkage of metabolomics data with genomics and proteomics data, and with health, lifestyle and clinical data will be critical to health and medical research and research translation, and in Australia could be achieved through, or assisted by, PHRN. Linkage to imaging data should also be considered.

Metabolic profiling would be valuable in augmenting clinical trials, e.g. in those conducted by WA's Linear Clinical Research, Australia's most advanced facility for early phase clinical trials (specifically first-in-human and first-in-patient).

As metabolomics can be applied to both fresh and archived samples, there is considerable potential in undertaking such analysis at a level not done before for samples from population health studies (including WA's Busselton Health Study and Raine Study) and other biobanks, and linkage of the metabolomics data to genomics, clinical and other data as discussed above.

The Office of Sciences sees significant merit in the establishment of a population biobank infrastructure in Australia for population genomics and research, and recommends the inclusion of population metabolomics. However, the optimum form of this infrastructure needs to be determined. For example, would it be best to establish a network of population biobanks with one in each state, or as a network of existing biobanks across Australia? Or if a national population biobank (akin to the UK Biobank) was established, rather than operating as a sole entity, perhaps it should be at the centre of a network that includes existing biobanks so that the value of their samples is not lost.

The expansion of metabolomics infrastructure that would be required to meet the demand for "industrial-scale" metabolite profiling to advance applications in the health and medical sciences would need to include metabolomics bioinformatics infrastructure for this data-intensive field. There would be an associated need for skilled metabolomics bioinformaticians. Data storage could involve the Pawsey Supercomputing Centre in WA. Data visualisation, although in its infancy, will be a powerful tool for interpreting metabolic analyses.

Identified emerging directions and research infrastructure capabilities:

5.2.6 Imaging

<u>Positron Emission Tomography (PET):</u>

One use of PET for research is in Alzheimer's disease research for imaging of beta amyloid (the protein fragment responsible for Alzheimer's disease [check wording]) in brain scans. The Australian Imaging, Biomarker & Lifestyle Flagship Study of Ageing (AIBL) is a study to discover which biomarkers, cognitive characteristics, and health and lifestyle factors determine subsequent development of symptomatic Alzheimer's disease. Participants in the study undergo structural neuroimaging scans with Magnetic Resonance Imaging and beta amyloid imaging PET scans.

AIBL involves a multidisciplinary research team from Perth, Sydney, Adelaide, Melbourne, Canberra and Brisbane. While all the data is currently collected in only Perth and Melbourne, data collection (including through imaging) may be expanded to other states in the future.

WA has only one cyclotron to generate products (tracer compounds) for PET imaging for research, which must compete with production of products for clinical use. There is a need to ensure that at a national level there is sufficient capacity to meet current and future anticipated demand for cyclotron products for research PET biomedical imaging.

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

Australia should engage in the current stage (FANTOM6) of the FANTOM (Functional AnnoTation Of the Mammalian genome) project, which is a worldwide collaborative project (including a data integration, data analysis and visualisation system) aimed at identifying all functional elements in mammalian genomes.

FANTOM6's goal is to systematically elucidate the function of long non-coding (non-protein coding) RNAs (lncRNAs) in the human genome. IncRNAs are part of the transcriptome, are important regulators of gene expression and have roles in development and diseases e.g. cancer. Professor Alistair Forrest (Harry Perkins Institute of Medical Research, WA) is the key person nationally to ensure Australia's linkage with FANTOM6 as he was scientific coordinator of FANTOM5, which involved a consortium from 20 countries (including Australia) and generated several major publications, including a number of *Nature* and *Science* papers.

4 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?

Identified emerging directions and research infrastructure capabilities:
6.1.1 Integration; 6.1.2 Climate & water resources; 6.2.1 Atmospheric observations; 6.2.2 Marine environment; 6.2.3 Terrestrial systems

<u>Marine:</u>

Australia has the third largest ocean territory on earth, which delivers massive economic benefits to the nation through industries such as offshore oil and gas, marine tourism, shipping, fishing and aquaculture, including those off the coast of WA.

The Integrated Marine Observing System (IMOS), a national research infrastructure since 2006, measures physical, biogeochemical and biological variables, from open-ocean onto the continental shelf and into the coast, with collected observations and data streams delivered through the open access Australian Ocean Data Network Portal. Operating as a multi-institutional collaboration, IMOS has partnerships with major Australian research initiatives such as the Marine Biodiversity Hub of the National Environmental Science Programme and the WA Marine Science Institution.

IMOS also provides a mechanism for the international collaboration required to understand a globally connected ocean. For example, IMOS is one of the 13 regional alliances of the Global Ocean Observing System, contributes to the Indian Ocean Global Ocean Observing System and supports the multinational second International Indian Ocean Expedition (2015-20) in which Australia is a partner.

The National Marine Science Plan (2015-25) includes sustaining and expanding IMOS as one of its eight high level recommendations. The Office of Science agrees with this recommendation, and with the Issues Paper's view that the marine environment capability should continue as a high priority.

WA's coastline (bordering the Indian Ocean, Timor Sea and the Southern Ocean) accounts for 33% of Australia's coastline. Two of Australia's four marine-based World Heritage areas and two of Australia's five marine bioregions are off WA's coasts. Marine environments of WA are strongly influenced by the warm Leeuwin Current, the world's longest continuous coastal current system, that flows southwards off the coast of WA, rounding Cape Leeuwin to enter the waters south of Australia where its influence extends as far as Tasmania.

WA's marine ecosystems are facing unprecedented pressure from coastal and offshore marine industries (including North West Shelf oil and gas production, and the expanding Pilbara port network), tourism, aquaculture and large coastal developments. IMOS and WA-IMOS (one of IMOS' six integrated nodes) are therefore important research infrastructure for WA, where sustainable development, conservation and management of the state's marine environment is crucial.

Potential options to extend IMOS in WA include enhancing the IMOS Rottnest Island National Reference Station (the only WA station in the current network of seven stations) to become a 'bluewater' satellite Ocean Colour calibration and validation site, and assisting to address observing gaps by:

- re-establishing the IMOS Ningaloo and Esperance National Reference Stations, which were decommissioned in 2014; and
- supplementing the IMOS Moorings Network assets (which hold a range of instrumentation) off Perth (Two Rocks/Perth Canyon) and in the Joseph Bonaparte Gulf (WA/NT) with mooring arrays in the Kimberley and Pilbara regions.

Marine research infrastructure should align with the National Marine Science Plan and the National Environmental Science Programme, and should also support and be relevant to:

- the national marine science community, including the WA Marine Science Institution whose focus includes research to support management of the Kimberley region's marine environments and marine dredging science, including in the Pilbara; and
- state marine plans, such as WA's Blueprint for Marine Science Initiative - Implementation Strategy 2016-18. The strategy guides the foundation of a long-term collaboration between industry, government, research and community around marine science, including sharing data.

<u>Coastal zone:</u>

The Office of Science considers that the Issues Paper is correct in identifying coasts as one of the sources of gaps in observing networks and in proposing that in the future the marine research infrastructure capability is expanded to include coastal zones.

The National Marine Science Plan recommends that IMOS be sustained as a national provider of open ocean and continental shelf observations, and expanded to serve as the national provider for estuarine and coastal observations, and advises that there is a need to integrate an extended IMOS with terrestrial observation systems (surface and groundwater, vegetation and soil). The Office of Science concurs with these proposed actions.

The majority of the 166 estuaries in WA lie in the Kimberley, but the most affected and changed estuaries are the 40 that lie in the South-West region. The major pressures affecting estuaries are a combination of human impacts (including population growth, urbanisation and agriculture), climate change and extreme events.

The WA Marine Science Institution is developing an estuary science program aimed at supporting healthy estuaries and the sustainable development of their catchments throughout WA. In August 2016, the Estuaries Science Steering Group released a consultation draft of the *Research and information priorities for estuary management in southwest WA* report prepared through consultation with researchers and estuary managers, including from the WA Departments of Water and Parks & Wildlife. Baseline monitoring data (including biophysical, chemistry and biodiversity) was identified as a key knowledge gap and there was common agreement that a modelling framework is required to understand how complex components of estuarine systems interact.

The new WA Biodiversity Science Institute is facilitating the strategic coordination and targeted application of research and knowledge to underpin the protection, conservation and sustainable management of WA's biodiversity (flora and fauna). The institute will cover all terrestrial biodiversity, which includes all freshwater systems and estuarine systems.

Just as the WA Marine Science Institution and the WA Biodiversity Science Institute overlap at estuaries, there should be research infrastructure collaboration in the coastal zone between IMOS and the Terrestrial Ecosystem Research Network.

Note that measurement of stable and radioactive isotopes in water, noted in sub-section 9.2.3 (Water security) of the Issues Paper as showing considerable promise, could be applied to catchment-estuarine systems as environmental tracers, e.g. to trace nutrient pathways.

<u>Terrestrial:</u>

Australia is one of 17 countries described as being 'megadiverse' (biological diversity). Many species native to Australia are found nowhere else in the world, including 84% of plant species and 83% of mammals.

WA has a particularly rich biodiversity. Eight of Australia's 15 terrestrial biodiversity hotspots are located in WA, as is the South-West Australia hotspot, which is the only Australian hotspot of the world's 35 major biodiversity hotspots as defined by Conservation International.

In light of the need to reconciling WA's economic and urban development with the conservation and management of WA's biodiversity assets, the Office of Science agrees with the Issues Paper's statement that the terrestrial systems capability continues as high priority. As a result, the Office of Science supports continuation (and enhancement where appropriate) of the Terrestrial Ecosystem Research Network (TERN) and the Atlas of Living Australia as national terrestrial systems research infrastructure, including to address the need for baseline/long-term data and data integration, and ecosystem and soil monitoring gaps.

Launched in October 2015, the WA Biodiversity Science Institute is an unincorporated joint venture between three WA universities, CSIRO, three State Government departments and three authorities, including the Botanic Gardens & Parks Authority and the WA Museum. Three of these participants are TERN partners, while a fourth is a partner in the Atlas of Living Australia. A key goal of the institute is improved management and access for biodiversity data gathered by government, research agencies and industry, including via supporting the development of a database for use as a public resource. The institute is initially focusing on WA landscapes in the Pilbara, Kimberley, South-West and the Western Desert Lands.

TERN has built a nationally coherent and multidisciplinary framework for the collection and delivery of critical data, tools and expertise for Australian ecosystem science where previously efforts were often uncoordinated and disjointed. Similarly, while WA's biodiversity research efforts had largely been fragmented and difficult to access, now the WA Biodiversity Science Institute draws together capabilities across all of the state's key research providers.

<u>Metabolomics:</u>

In addition to the application of metabolomics in health and medical research and research translation, there are also considerable opportunities associated with linking metabolomics data with genomics data and proteomics data in other areas including animal production, crop production, food and beverage, and environmental areas such as biodiversity, coral reef health and wildlife conservation.

<u>Water (also covered under the Issues Paper's National Security capability focus area):</u>

In addition to the coastal zone, another valuable area of expansion for TERN would be to include a national capability for monitoring freshwater ecosystems.

The Office of Science shares the Issues Paper's opinion that water security remains a critical element requiring ongoing capability development in its own right. In WA, water security is a key challenge for a state that covers the tropics to the arid inland, and that must balance water demand from urbanisation, the mining and energy sector and agriculture with the natural environment's water needs against the background of climate change, including a drying South-West region.

The WA Department of Water plays an important role in water science and water resource identification and management. For example, it leads the Royalties for Regions-funded Water for Food initiative, for which a key objective is identification of water resources in WA, including via groundwater investigations in the Kimberley and the Mid-West regions.

National capabilities that would assist with water security going forward include modelling approaches for surface and groundwater interactions, improved rainfall/runoff (flood) modelling techniques, geophysical and other remote sensing tools for groundwater surveys, and monitoring networks utilising the Industrial Internet of Things, plus capabilities associated with aquifer recharge.

Identified emerging directions and research infrastructure capabilities:

6.2.4 Solid earth

<u>Characterisation and modelling:</u>

The importance of the minerals and energy resources sector to the Australian economy justifies continuing funding for existing and new geoscience characterisation and modelling research infrastructure.

Options for building on research infrastructure in this area include:

- further development of AuScope's National Virtual Core Library, which includes imaging and mineral characterisation of drill cores from seven State and Territory geological surveys, including the Geological Survey of WA; and

- a new 3D geological/geophysical virtual laboratory that includes 3D geological modelling capabilities (such as those being developed by WA Fellow Professor Mark Jessell in collaboration with the Geological Survey of WA).

Additional research infrastructure capabilities needed:
Additional capability – Soil microbial diversity:

While the Issues Paper refers to capability gaps related to soil (carbon, water, nutrients flow), the Office of Science considers that national capability related to soil microbial biodiversity also needs to be further developed. This would build on Bioplatforms Australia's Biome of Australia Soil Environments project which is creating a reference map of Australia's soil based on DNA sequencing (the partners include the Atlas of Living Australia and the Australian National Data Service), and the work of WA Fellow Professor Andrew Whiteley who is doing the same for WA's soils.

Soil microbes play an important role in soil nutrient and carbon cycling, and have critical relationships with plants. Soil microbial biodiversity data could be linked to other data sets (e.g. vegetation, land use and soil characteristics through further development of the Soils-to-Satellites online tool), plus incorporated into the Atlas of Living Australia, to enhance Australian ecosystem knowledge and contribute to land management strategies (e.g. for agriculture and mine site rehabilitation).

Additional capability – Plant biodiversity:

The Office of Science suggests that the plant equivalent of human biobanks would be valuable research infrastructure for Australia. A national seed/tissue culture bank could be established, perhaps as a network of seed/tissue culture banks with one in each state, based on the Australian Seed Bank Partnership which has partners in each state. The WA partners are the Botanic Gardens & Parks Authority's WA Seed Technology Centre and the Department of Parks & Wildlife's Threatened Flora Seed Centre (Flora Conservation and Herbarium Program).

Extra value would be added by linkage of the national seed/tissue culture bank to a database of genomic and metabolomics analysis, as well as taxonomy data, for the plants for which seed/tissue culture is stored in the bank, which could build on the Australian Seed Bank Partnership's virtual seed bank that is available online through the Atlas of Living Australia website. Applications could include conservation, habitat restoration and biodiscovery (utilising metabolite profiling).

5 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?

Identified emerging directions and research infrastructure capabilities:
7.2.1 Astronomy & cosmology

Radio astronomy:

The Office of Science strongly supports continued research infrastructure funding through Astronomy Australia Ltd for operations of two of the Square Kilometre Array (SKA) precursor telescopes that are laying the foundation for the SKA radio telescope. These telescopes – the Murchison Widefield Array (MWA), which is an international collaboration, and CSIRO's Australian Square Kilometre Array Pathfinder (ASKAP) – are located in WA at the future Australian SKA site.

In addition to providing crucial design, assembly and deployment guidance for the SKA, the MWA and ASKAP are world-leading radio telescopes in their own right. While a $1 million Australian Research Council Linkage Infrastructure, Equipment and Facilities scheme grant was awarded in 2015 to expand the capacity of the MWA (including doubling the number of telescope antennas), ongoing operations funding will be needed to maximise the benefit of this capital funding.

As noted in the Issues Paper, radio astronomy requires massive data storage and high performance computing capability. The WA State Government currently provides support for the MWA and ASKAP through funding for the Pawsey Supercomputing Centre, and for the International Centre for Radio Astronomy Research, which is playing a key role in supporting ASKAP science and data management, and in extracting new scientific results from MWA data.

Funding of $294 million over 10 years was announced in 2015 as part of the Australian Government's National Innovation and Science Agenda to meet Australia's initial commitment to the SKA: this includes funding for construction (commencing in 2018 at this stage) and early SKA Phase 1 operation (to 2025-26). However, the Office of Science wishes to flag that consideration should be given to the need for future funding for continuing SKA operation (from 2026-27), which will have an anticipated lifetime of 50 years. Furthermore, funding sources for essential Australia-based research infrastructure for SKA data processing, and production and distribution of science data products, have not been identified.

Identified emerging directions and research infrastructure capabilities:

7.2.2 Fabrication & processing

Nano and micro technologies:

The Office of Science agrees with the Issues Paper's view that existing fabrication capabilities should be continued, with an enhanced fabrication focus in the future on packing and integration capabilities.

The Australian National Fabrication Node (ANFF) provides a network of national research infrastructure and expertise to support research and development in advanced manufacturing (related to fabricating materials, objects or devices at the micro and nano scales). This fosters Australian research competence in the micro/nanotechnology sphere that will dominate manufacturing and technological processes in the future.

Micro/nanofabrication is relevant to all the National Science and Research Priorities (and to six out of seven capability focus areas identified in the Issues Paper). ANFF facilities exist to allow the fabrication of complex structures at the cutting edge of materials science, nanoelectronics, nanophotonics and nanomedicine, and developments in areas as diverse as quantum computing, sensors (including emerging technologies in sensors for environmental monitoring), energy storage and medical diagnostics. ANFF has the capacity for expansion to accommodate new technologies.

ANFF's WA node is one of eight nodes, each with a distinct set of fabrication capabilities. The WA node provides researchers and industry with access to the following two flagship capabilities (and overlap of these capabilities): infrared sensing technologies and on-chip microelectromechanical systems (including towards development of chips with biological and chemical sensor arrays for medical, chemical and food security applications). These capabilities have significant demand for access, including from industry. An enhanced focus on packaging and integration capabilities would directly align with, and be relevant to, the WA node.

Identified emerging directions and research infrastructure capabilities:
7.2.3 Imaging & analytics

Characterisation and imaging:

Both imaging and characterisation capabilities are on offer at WA's Centre for Microscopy, Characterisation & Analysis (CMCA), whose research infrastructure supports research spanning biological, biomedical, chemical, earth and environment and physical sciences. The CMCA is the WA node of two national research infrastructure facilities, namely the Australian Microscopy and Microanalysis Research Facility and the National Imaging Facility.

The Australian Microscopy and Microanalysis Research Facility and the National Imaging Facility should be well-placed to address the increasing convergence of imaging and characterisation capabilities, including around shared technology, application, and multi-modal tools and data integration. New instrumentation is likely to be needed as national research infrastructure as a result, and also to ensure access to any new technologies that are needed to keep Australia at the cutting edge internationally for characterisation and imaging.

The Office of Science notes that WA currently has no human medical imaging infrastructure dedicated to research, which is a significant gap. Such infrastructure is needed to support human brain and body imaging for research, including in the future through the new Sarich Neuroscience Research Institute at the Queen Elizabeth II Medical Centre. The institute (to be completed in late 2016) will house five of WA's neurological research organisations, including the Ear Science Institute of Australia, the McCusker Alzheimer's Research Foundation and the WA Neuroscience Research Institute. The gap could be addressed through the National Imaging Facility (which currently provides human imaging infrastructure for research in Queensland, New South Wales and Victoria).

6 National Security

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

Identified emerging directions and research infrastructure capabilities:
9.1.2, 9.2.2, 9.3.2 Cyber security

The Office of Science acknowledges the risks and opportunities across Australia associated with the cyber landscape, with particular risks in WA's minerals and energy resources sector, and the critical need for dedicated infrastructure to support collaborative cyber security research. The threats and risks are set to increase in Australia with vulnerabilities around the emerging trend of the Internet of Things and the Industrial Internet of Things.

The Issues Paper proposes that ideally cyber national infrastructure would be a federated architecture that would have new capability but would include existing infrastructure available across the research community. The Office of Science agrees with this view.

There are major WA-based cyber research capabilities in industry (e.g. Cisco, Thales, Woodside, Rio Tinto), Curtin University and Edith Cowan University (ECU). The ECU Security Research Institute has significant cyber security capabilities in terms of both people and purpose-built facilities, with particular expertise in digital forensics; privacy; and control and data acquisition systems responsible for critical infrastructure (e.g. water, gas, electricity, sewage, remote mining operations, oil and gas extraction). The institute would make a valuable contribution if integrated into cyber national research infrastructure.

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

With respect to international collaborations there is a sovereignty issue that makes the development of capability within Australia imperative. However, this does not negate the need for international collaborations with countries that are world leaders in cyber security, such as Israel and the US.

7 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?

Identified emerging directions and research infrastructure capabilities:
10.1.1 eResearch infrastructure; 10.2.1, 10.3.1 High performance computing

The Office of Science concurs with the Issues Paper's call for consideration of a four year capital cycle for the two 'Tier 1' high performance computing facilities, namely the Pawsey Supercomputing Centre (Pawsey) in Perth and the National Computing Infrastructure (NCI) in Canberra. Pawsey is exploring stronger strategic linkages with NCI.

Pawsey offers world-class facilities and expertise in high performance computing, data and visualisation to support a range of applications across industry and research in Australia. Pawsey services key scientific areas such as radio astronomy, bioinformatics, resources science and energy research, ensuring Australia remains internationally competitive in sectors of national significance.

The Office of Science notes that Pawsey will need funding committed in the near future for upgrades to ensure the centre can meet the existing and growing needs of users, and requirements for provision of supercomputing and data storage support for the MWA and ASKAP (the SKA precursor telescopes in WA). Pawsey's peak supercomputer Magnus will need to be replaced in the next two years, and its Galaxy supercomputer (for the MWA and ASKAP) will need replacing around 2018. Additional data storage infrastructure will also be needed. However, there is currently no funding allocated to Pawsey for this capital refresh.

Pawsey is currently a member of the Science Data Processor (SDP) Consortium of the SKA, which is responsible for designing the computing environment that will process data from the SKA telescope to produce radio astronomy data products. While it is likely that the SDP for the SKA Phase 1-low telescope (the Australian component of SKA Phase 1) will be located at Pawsey, the exact SDP requirements are not yet known, but could be addressed through a ramping up process. Funding requirements and sources have yet to be determined.

The WA State Government is currently supporting Pawsey with funding of $21.55 million over five years (2016-21) for employment of specialised staff, operational expenditure and development of computational science professionals. This funding is supporting Pawsey to strengthen its position as a state, national and international supercomputing centre; deliver cutting edge high performance computing and big data solutions that benefit WA; support WA State Government science priorities; support the development of WA's capability in data intensive science; and assist in maximising the benefits of the SKA project.

8 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?

Additional research infrastructure capabilities needed:
Additional capability – Data visualisation:

The Office of Science recommends that data visualisation should be added as a specific capability – it is multidisciplinary and cuts across all of the Issues Paper's capability focus areas. Examples of existing data visualisation research infrastructure that could form the nucleus of national infrastructure are WA's Pawsey Supercomputing Centre and Curtin HIVE (Hub for Immersive Visualisation and eResearch), and the EPICentre (Expanded Perception and Visualisation Interaction Centre) at the University of New South Wales.

9 Other Comments

Funding for national research infrastructure needs to be for both capital and operating expenses of this infrastructure, and capital funding should include funding for repairs or upgrading of equipment as deemed necessary to maintain equipment at the cutting edge internationally.

National research infrastructure associated with different capabilities should collaborate where possible, as has occurred between the Terrestrial Ecosystem Research Network, the Atlas of Living Australia and the Australian National Data Service on the Soils-to-Satellites online tool.

In the event that funding through the Australian Renewable Energy Agency does not continue, it is recommended that examination of national research infrastructure capabilities related to renewable energy research and research translation, including associated with battery storage, should be undertaken.

Further details on specific capability needs for water science (of which only some key needs are summarised in the response to question 18) are available on request from the WA Department of Water