Please note: the substantive content of the 2026 NRI Roadmap Survey begins at Question 20 (with prior questions dealing with administrative and other information).

As such all submissions that are published include the responses submitted from Question 20 onwards only.

Q20.

Part 2: Research themes

2.1 NRI comprises the assets, facilities and associated expertise to support leading-edge research and innovation in Australia and is accessible to publicly and privately funded users across Australia and internationally. We are seeking your input on possible directions for future national-level investment - i.e., where the requirements are of such scale and importance that national-level collaboration and coordination are essential.

The 2021 Roadmap used a challenge framework to support NRI planning and investment. With this in mind, consider likely future research trends in the next 5 - 10 years, and with respect to one or more of the 8 challenge areas identified in the 2021 Roadmap as listed below:

- describe emerging research directions and the associated critical research infrastructure requirements that are either not currently available at all, or not at sufficient scale and
- describe current national infrastructure requirements that you anticipate will no longer fit the definition of NRI in 5-10 years.

Do not limit your commentary to NCRIS funded capabilities.

Q21.

Resources Technology and Critical Minerals Processing

Establishing the geographical provenance of critical minerals (in ore, mixed-oxide, pure oxide, or metallic form, including but not limited to rare-earths) is likely to grow in importance over the next 5-10 years. This is due to continuing strategic great-power competition for control over critical minerals and their essential role in the transition to a zero-emissions economy. Research is needed to determine how such minerals can be 'fingerprinted' to a particular geographic region or ore body. For example, the European Union recently passed its European Critical Raw Materials Act, seeking to increase and diversify the EU's critical raw materials supply, strengthen circularity, including recycling and support research and innovation on resource efficiency and the development of substitutes. It is therefore in Australia's strategic and economic interest to develop methods to establish the provenance of Australian -sourced critical minerals for export to like-minded nations. NRI - particularly the NEESF and M2M clusters - will play a vital role in supporting researchers to develop these capabilities. NRI needs to be better connected to support the research community in testing complementary physical and chemical techniques needed to achieve this goal: the required infrastructure is likely to be expertise as much as equipment/physical infrastructure.

Q22.
Food and Beverage

As the global climate changes, new forms of climate-resistant crops are needed to feed our populations. A vitally important research technique is heavy-ion beam mutagenesis (see for example https://doi.org/10.1016/j.nimb.2013.05.026) which is a particularly efficient method of inducing mutations in plants due to its high linear energy transfer compared to other methods such as x-ray and gamma-ray irradiation. China's second most widely-grown variety of wheat, Luyuan-502 (see How Nuclear Techniques Help Feed China | IAEA), was developed following radiation exposure of wheat seeds in low-earth orbit, giving them unique drought and disease-tolerant qualities. The same technique can be performed on earth by exposing seeds to beams of heavy-ions from particle accelerators. Australia requires sovereign RI capabilities to ensure our continued food security. A key gap in Australia's NRI for this technique is the availability of heavy ion beams with sufficient energy to penetrate into seed DNA. For example, HIAF can produce carbon-12 beams with energies of up to 105 mega-electron volts (MeV), but energies ten times greater are needed to efficiently and effectively produce mutations in a range of seeds. Currently, researchers send samples to Japan for irradiation, requiring export and import permits, quarantine procedures an lengthy delays. Early tests of irradiation of wheat seeds with proton beams have been performed at HIAF during 2024, and the results are expected shortly, however, the lower energies at HIAF compared to facilities such as RIKEN in Japan severely constrain our ability to meet the needs of Australian researchers.

Q23.
Medical Products

The use of radiopharmaceuticals for theranostic (therapeutic-diagnostic) applications is a rapidly growing field in Australia and worldwide. Radiopharmaceuticals are biologically active compounds labelled with radionuclides to provide a source of ionizing radiation for diagnosis and therapy. Over the past two decades, one of the most significant outcomes of the human genome project in nuclear medicine has been the development of theranostic radiopharmaceuticals that are based on patients' disease genotypes and phenotypes and that are labelled with radionuclide pairs. Through their exquisite sensitivity and specificity, these nuclear theranostics, in combination with sophisticated high-performance digital hybrid imaging techniques (SPECT/CT, PET/CT, and PET/MRI), have started to play a major role in precision medicine by significantly improving patient disease management, particularly in oncology. • More recent developments include the radiolabeling of metallic, polymeric, silica, dendrimer and liposome nanoparticles to form theranostic systems which show considerable promise in targeting specific tumour types with higher doses of radiation. • Targeted alpha therapy (TAT) is a relatively new field which uses alpha-emitting isotopes (such as 225Ac, 213Bi, 212Pb and 211At) to deliver short-ranged radiation doses to cancer cells after transport by carriers such as monoclonal antibodies to area of concern. Because of the high impact on disease management, and cancer in particular, the utilisation of radiopharmaceuticals, including novel radiopharmaceuticals, is increasing dramatically in Australia. In particular, the number of positron emission tomography (PET) scanners in Australia, which are often involved in theranostic applications, has increased ten-fold in the last 15 years. But Australia's capacity to support clinical trials to develop new radiopharmaceuticals to meet the growing demand is limited – in part by beamtime capacity and infrastructure at its limited number of cyclotron facilities. o Cyclotrons – required to produce radioisotopes – are expensive to build and require ongoing sustainment and a skilled workforce. o Infrastructure capacity and capability to support and translate research into new alpha-emitting isotopes for TAT applications is a key gap in Australia. o Current facilities are committed to meeting demand for existing radioisotopes, such as 11C, 18F and 89Zr (PET radiotracers), 99Tc (diagnostics) and 131I (thyroid diagnostics and treatment o Australian hospitals and researchers rely heavily on the OPAL reactor at ANSTO in Sydney, for a limited supply of 177Lu used for endocrine and prostate cancer therapy and for a range of future therapeutic applications. Although 177Lu cannot easily be produced in a cyclotron, other radioisotopes with similar properties can be produced with cyclotrons, which in turn will enable support for more clinical trials across Australia.

Q24.
Defence

Defence will continue to require a nuclear-literate workforce to support AUKUS (both Pillars One and Two). Educating this workforce requires sufficient numbers of high-quality physicists at Australia's tertiary institutions, many of whom will have to come from overseas due to the limited number of nuclear physicists in Australia. Australia's nuclear research infrastructure (primarily at HIAF) will continue to play a critical role in attracting international talent to Australia, provided the facilities remain internationally competitive. Defence is has growing requirements for novel materials and devices, such as high-performing infra-red detectors, quantum sensing devices and energy storage methods. AUKUS Pillar Two will continue to drive demand for these and related capabilities, meaning that our materials science infrastructure will need to keep pace with demand if we are to keep researchers onshore. This infrastructure includes accelerator-based ion implantation infrastructure needed for the precise, subtle and flexible modification of materials such as silicon, and diamond with a variety of carefully introduced ion species. Further requirements are likely to include accelerator-based testing capabilities for materials essential for nuclear propulsion, such as cladding materials for nuclear fuel and radiation shielding materials.

Q25.
Recycling and Clean Energy

Australia’s solar cell research will continue to depend on ion-beam analysis techniques using particle accelerators. HIA has long supported researchers in this field, including testing of perskovite materials for solar cells and the impact of contaminants of their performance. Such testing is also essential to understand the performance of new solar cell materials deployed for space-based applications. Accelerators also help improve the efficiency of existing energy storage methods, such as improvements to lithium-ion batteries. Australia’s ion accelerators and ion beam analysis techniques must continue to evolve to support solar cell and clean energy research.

Q26.

Space

As the Australian space industry grows, the demand for space-testing services such as those for electronic components, novel radiation shielding materials and radiation-resistant plants increases correspondingly. As Australia’s only heavy-ion testing facility, HIAF is meeting some of this demand, but it cannot produce beams at sufficiently high energies found at laboratories in the USA, Japan or Europe: these energies are needed to secure certification to internationally-recognised test standards (such as the JEDEC standards JESD57A and JESD234), hindering the growth of our space industry. Further, international facilities have multi-year wait times and prohibitively-high user charges (thousands of USD per hour), beyond the reach of Australian industry. We therefore have a gap in our translation research infrastructure, namely the ability to produce heavy ion beams with energies of 100 MeV/nucleon or greater (10-20 times higher than currently available). This is the same energy scale needed to support Australia’s plant researchers in developing climate change-resistant crops.

Q27.

Environment and Climate

Australia’s groundwater is critical for our nation’s food security, agriculture, industry and the sustainability of our communities, particularly those in regional and remote Australia. The National Groundwater Strategic Framework 2016-2026 states: “The economic value of production to the Australian economy supported by groundwater is estimated to be $33.8 billion. This is comprised of metal ore mining $24.8 billion (73 per cent), agricultural production dependent on groundwater $3.7 billion (11 per cent) and agricultural livestock in groundwater dependent areas $1.0 billion. Groundwater represents significant water security at times of limited alternative water supply for various types of agricultural, mining and industrial production throughout Australia, underpinning investment in these sectors. Further, it is important to note that groundwater resource development and use typically involves costs associated with treating water." Australia’s groundwater makes up approximately 17% of our accessible water resources, and accounts for over 30% of national water consumption. It is particularly important in arid or semi-arid parts of Australia where rainfall is too infrequent to reliably meet water needs. Often such groundwater resources have accumulated over long periods and are replenished only when rainfall is sufficient to infiltrate soil and rock. This means groundwater is a finite, or slowly replenished resource. It is a resource increasingly under threat due to overuse, seawater intrusion, flooding events, pollution and climate change. Understanding the age of Australia’s groundwater is essential for a sustainable groundwater management strategy. Such a strategy requires reliable estimates of groundwater residence time (age), recharge and discharge rates. These timescales span tens of years to millions of years, and can be determined through measurements of trace quantities of tritium (half-life 12.3 years), carbon-14 (half-life 5730 years) and chlorine-36 (half-life 300,000 years) found in groundwater. Electrostatic ion accelerators – as used at HIA, the ANU Radiocarbon Facility and ANSTO – possess the required high sensitivity and precision for these measurements using proven techniques belonging to the discipline of accelerator mass spectrometry (AMS). HIA, the ANU Radiocarbon Facility and ANSTO are experiencing increasing demand for the dating of ground water samples from Australia’s research community – demand that cannot be met by any single facility in isolation. Further, groundwater data must be high quality and accessible to Australia’s researchers and policy makers: quality control will be built-in through cross-verification between accelerator facilities, while incorporation of groundwater data into AuScope’s Sample Repository using persistent identifiers will ensure ready access to groundwater data and metadata in accordance with the FAIR Data Guiding Principles.

Q28.

Frontier Technologies and Modern Manufacturing

Quantum sensing uses quantum mechanical phenomena, such as superposition, entanglement, and interference, to measure physical properties—like time, magnetic fields, temperature, or acceleration—with incredibly high sensitivity and accuracy. The National Quantum Strategy identified sensing as the quantum technology that will provide the earliest practical, scalable applications to fields as diverse as medicine, navigation, timing, advanced imaging and the discovery of critical minerals . Australian researchers are delivering breakthroughs in the production of diamond quantum sensors with the ability to detect biomagnetic fields in the heart and brain , tackle neurological diseases , provide geolocation and navigation for GPS-free environments , and provide early detection of tumors through magnetic imaging of cancer biomarkers . Ion-implantation is used to create quantum centres in the near-surface of materials and provides a critical platform for quantum research and development in Australia. However, there is a key gap in the research infrastructure that is slowing innovation and translation of quantum sensing schemes into testable prototypes. This relates to the fact that many of these new and emerging applications require ultra-shallow implants and/or very high implantation temperatures, neither of which are currently available. This means that Australia researchers travel to facilities overseas for low-energy implantation services, introducing logistical delays, slowing innovation and incentivising the transfer of knowledge offshore. Demand for RI capable of fabricating quantum centres for sensing applications is very likely to persist for the next decade and beyond Another frontier technology receiving increasing attention for a rich variety of practical applications is that of solid-state nanopore sensors. These are being used for rapid DNA sequencing, including single-molecule sensing of protein bio-markers for neurodegenerative diseases. the development and testing of machine learning data evaluation methods, water filtration and desalination and lab-on-the-chip applications. These nanopores are produced by the high energy bombardment of solid-state materials by heavy ions (eg gold ions) such as the Heavy Ion Accelerator Facility, located at the ANU. However, to remain relevant to this growing field, Australia will need access to higher energy beams, which are currently only found overseas, such as those at the GSI Helmholtz Centre for Heavy Ion Research, in Germany.

Q29.

2.2 The 2024 statement of National Science and Research Priorities (NSRPs) includes outcomes linked to each priority to assist in identifying critical research needed in the next 5 to 10 years.

Consider the priority statements and, with respect to one or more of the 5 priority areas as listed below:

- describe emerging research directions and the associated critical research infrastructure requirements that are either not currently available at all, or
- not at sufficient scale and describe current national infrastructure requirements that you anticipate will no longer fit the definition of NRI in 5-10 years.

Do not limit your commentary to NCRIS funded capabilities, and where relevant, refer to the underpinning outcomes and research identified in the NSRPs document.

Q30.

Transitioning to a net zero future

Please see our earlier response regarding critical minerals, particularly rare-earth minerals.

Q31.

Supporting healthy and thriving communities

Please see our earlier responses regarding development of climate-change resistant crops, and the development of new radiopharmaceuticals for cancer theranostics.

Q32.

Elevating Aboriginal and Torres Strait Islanders knowledge systems

For the 60,000 years that Aboriginal peoples have lived in Australia, water has played a critical role—not just for survival in an often arid and harsh environment but also for its significance in Aboriginal culture and identity. Water helped in defining language boundaries and ceremonial places and also underpins many land management practices. We can improve our understanding of Australia's groundwater resources by integrating Indigenous knowledge of water resources, water management and groundwater flows with research practices employing dating methods such as those provided by accelerator facilities such as HIA and ANSTO. This knowledge in turn, can assist Indigenous communities in their continued stewardship of the essential resource which is under threat from climate change, overuse and pollution.

Q33.

Protecting and restoring Australia's environment

Please see our earlier response regarding Australia's groundwater resources, namely the information needed to sustainably manage this essential national resource.

Q34.

Building a secure and resilient nation

Please see our earlier response regarding Australia's groundwater resource and Defence requirements.

Q35.

2.3 The case for a new NRI capability, or enhancements to existing capabilities, typically emerges through advocacy from research communities clustering around rigorously identified needs and goals. Such a concept could respond to a requirement for novel or expanded capacity within a domain, or across domains, and must be such that it could only be made available with national-level investment.
If you have identified such a requirement, briefly describe the need, the proposed infrastructure capability, the medium-term goals, impacted research communities, and the timeframe over which you advocate its establishment. Your response can include links to relevant existing reports.

For Australia to continue to support groundbreaking, sovereign research in plant science, medicine, fundamental nuclear science, environmental and climate research, and to support the growing space sector, there is a need to increase our capability to accelerate ion beams to higher energies, and with higher intensities, across a broad range of the periodic table. The desired end-state capability is a substantial upgrade to the HIAF Superconducting Linear Accelerator (LINAC) to more compact, contemporary technology by 2040, allowing for at least a doubling in the maximum beam energy currently available. The technology for such an upgrade to the HIAF LINAC is well-proven, operating successfully and reliably at facilities in the US, Europe and South Korea. The new LINAC would be coupled with a stand-alone ion source to enable an increase in the range of beam species and beam intensities currently achievable at the facility. This new capability would establish HIAF as world-class translational RI in support of radiobiology, plant science, nuclear medicine, space technology and fundamental nuclear physics. It would maintain Australia as an internationally competitive destination for nuclear science, attracting high quality researchers from a range of disciplines to come to Australia to conduct research, and/or take up positions in Australian tertiary institutions. It would also allow independent operation of the parallel, continually-used and still in-demand 14UD Pelletron accelerator, increasing support for climate and environment research such as groundwater dating and environmental monitoring, underpinning social license for AUKUS and responsible storage of Australia's nuclear waste. Important intermediate steps in establishing this capability would include growing the specialist engineering workforce to install and maintain the LINAC and establishing the building and other infrastructure requirements to house the new facility. The workforce component would leverage relationships with comparable facilities in the US and Japan, who would play an important role in developing our engineering base. Ideally, these components would be in place no later than 2035. For more than 50 years, Australia's accelerator facilities have rewarded forward-looking investment. Their innate versatility, ability to pivot to the scientific priorities of the day make them a low-risk, high benefit investment in national research infrastructure. They serve a broad and diverse research community in the service of the national interest, they serve as important symbols of our Australia's scientific credibility on the international stage, and they are integral to building scientific and diplomatic links in Australia's region.

Q36.

Part 3: Industry perspectives

This section is seeking input specifically from industry-based respondents. Other respondents can skip this section.

Recommendation 6 of the [2021 Roadmap] related to improvements in industry engagement with NRI. To complement work on this topic that has occurred since then, we are seeking additional advice on NRI requirements as perceived by current or potential industry-based users.

Q37.

3.1 Have you (or your organisation) interreacted with or used Australia's NRI?

- [x] Yes
- [ ] No

Q38.
3.2 If so, please briefly outline the NRI capabilities you (or your organisation) have interacted with or used. Do not limit your response to NCRIS capabilities.

Q39.
3.3 Please indicate your (one or more) primary reasons for interacting with NRI:

- [ ] For expertise or advice
- [ ] Access to research resources or products
- [ ] Access to equipment for research
- [ ] Access to equipment for operational reasons
- [ ] Help in translating research
- [ ] Access to data
- [ ] Support for clinical trials
- [ ] Other (please specify)

Q40.
3.4 If you answered no, please indicate your (one or more) primary reasons:

This question was not displayed to the respondent.

Q41.
Part 4: Other comments
4.1 Please elaborate on any of your above responses or add any other comments relevant to the development of the 2026 Roadmap. Your response can include reference or links to existing reports that you recommend be considered during the 2026 Roadmap development process.

Please consider the following publication: "Discovery Machines: Accelerators for Science, Technology, Health and Innovation" produced by the Australian Academy of Science. Although a few years old, it contains many still-relevant observations for the role of accelerators as a versatile investment for filling gaps in national research infrastructures. https://www.science.org.au/support/analysis/reports/future-science-discovery-machines-accelerators-science-technology-health