

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

An emerging research direction is the development of new materials for sustainably harvesting critical minerals such as lithium. Powerful electron microscopes, including nationally unique instruments, have been critical to such work, as exemplified by the research of Prof. Huanting Wang at Monash University and his spin-off company ElectraLith. Research in lithium extraction is a national endeavour, with activities at ANSTO, CSIRO, University of Queensland, Edith Cowan University...etc. Improvement of lithium-harvesting technology requires characterisation at the atomic scale of lithium and its behaviour within the newly designed materials. Lithium, being the third lightest element, is extremely difficult to detect, locate and map at the nanoscale, let alone the atomic scale. There is a critical need for national infrastructure that can identify the position, bonding and dynamics of individual lithium atoms within atomic structures. Determining the journey of lithium atoms in a lithium-harvesting material so that this material can be optimised or better designed will require new infrastructure that includes next-generation transmission electron microscopes able to combine measurements of atomic structure with electronic structure and time-resolved measurements, and to do this with the lowest possible electron dose, requiring electron microscopes with ultrafast, high dynamic range single-electron detectors. This technology would also be highly beneficial to research in other lithium-containing or light-element containing materials, such as batteries, solar cells, green catalysts and ultra-high-strength lightweight alloys for structural applications.

Q22.

Food and Beverage

Current research directions relevant to this challenge area include improving food processing and packaging, with emerging focus on recycling and sustainable processes. This requires the characterisation of structure and its multi-scale evolution, down to the nanoscale, and hence the use of electron microscopy. As an example, this capability has been critical to research and commercialisation projects of the Bioresource Processing Institute of Australia (BioPRIA). The materials involved are in most cases very sensitive to electron irradiation, so new instruments able to “probe gently” (i.e. use minimum electron dose) whilst affording high resolution and sensitivity will enable a broader range of such materials to be characterised.

Q23.

Medical Products

Emerging research directions in this area include: • New biodegradable implants based on metal alloys, e.g. zinc (see recent work by Monash, UNSW and international team, Wu et al. Nature, 2025) magnesium, titanium. • Nanomaterials for drug delivery such as targeted chemotherapy. • Scaffolds for the synthesis of artificial tissues and bones. • Sensors for the detection of biomolecules such as glucose or insulin, or for blood typing (e.g. as developed by BioPRIA and commercialised by Haemokinesis). • Nanomaterials for virus test kits such as for detecting the COVID-19 virus. Most of the above research aims to enhance Australia’s sovereign capability. The design and optimisation of such materials for the desired properties requires characterisation of their structure and chemistry at the nano- and atomic scale. This is extremely challenging, as these biomaterials are invariably very delicate. These materials typically need to be examined at the temperature at which they function (often room or body temperature). This necessitates electron microscopy instrumentation that can collect rich information about the material using minimal electron dose, requiring electron microscopes with ultrafast, high dynamic range single-electron detectors. It also involves the characterisation at the atomic scale of hard-soft interfaces (e.g. in the case of some drug delivery mechanisms, a “hard” nanoparticle with functionalised “soft” ligand on its surface). This requires new transmission electron microscope imaging technologies to enable the ability to image simultaneously the atoms on both the hard and soft side of the interface – again requiring electron microscopes with ultrafast, high dynamic range single-electron detectors.

Q24.

Defence

Military applications rely heavily on materials able to operate in extreme environments or exhibit ultra-high performance. Current and emerging research directions include the development of: • Alloys and composites exhibiting ultra-high strength relative to weight, strong corrosion resistance and/or robustness under heavy neutron irradiation • Materials for communication and sensing. • Low-energy electronics • Quantum computing and Quantum materials The properties of such materials commonly rely on a few, very specific atoms within the matrix (e.g. at a precipitate in a metal alloy or a qubit in a quantum computer). There is therefore a need for electron microscopes that can locate and identify such atoms and their bonding environment at the atomic scale, without altering them, again requiring electron microscopes with ultrafast, high dynamic range single-electron detectors. There is also a need for the ability to apply stimuli to these functional materials, such as extreme temperatures (furnace and Liquid Helium), forces, gases and currents. For photonic communication and sensing systems, there is a need for electron microscopes with ultrahigh energy (<5meV) and time resolution, currently not available in Australia.

Q25.

Recycling and Clean Energy

Addressing this challenge area requires designing more performant and safer batteries, solar cells, green catalysts as well as materials that can be more sustainably recycled. The rational design of such advanced materials necessitates knowledge of their atomic-scale structures. As already mentioned, lithium is a key component of many of these materials that is particularly challenging to probe. Doing so at the atomic scale demands new infrastructure, and in particular next-gen electron microscopes. Such instruments will also enable the measurement of key properties inside the microscope (e.g. optical, electrical or mechanical properties), allowing structure-property correlation at very high resolution. More efficient recycling and usage of material resources require knowledge of how and what contaminants are present, and where. The design of new materials such as more recycling-friendly aluminium alloys or steels also involves determining the location of critical atoms with great accuracy. This will only be possible with the most powerful and sensitive transmission electron microscopes.

Q26. Space

As for defence applications, space exploration will require advances in materials able to function in extreme environments, whether for structural applications, communication or as part of scientific instrumentation. These include: • High-performance alloys • Low-energy electronics • Quantum computing • Communication and sensing. Next generation electron microscopes with the ability to cool the specimen to extreme temperatures (liquid He) will be critical to designing and testing such materials.

Q27. Environment and Climate

As described above, clean energy materials constitute an important research area, with focus on: • Solar cells • Batteries • Green catalysis • Lithium extraction In addition to these, a large class of materials (membranes, porous nanomaterials) are being developed to solve important problems such as pollution or ensuring clean water. An example is a composite material that can desalinate water under sunlight only (Ou et al., Nature Sustainability 2020); electron microscopy was instrumental to this work. Understanding how these materials function, e.g. by locating their active sites, will necessitate newer, more capable electron microscopes Other important materials in this area include those developed for decarbonising key industrial processes, such as the production of ammonia (a major source of fertilisers as well as CO₂ using the current industrial production methods). A more environmentally friendly process (Du et al. Nature 2022, Suryanto et al, Science 2021) and under commercialisation (Jupiter Ionics start-up) would not been developed without advanced electron microscopy. This case involves lithium-containing materials, which, as mentioned above, cannot be fully characterised with present capabilities. The ability to examine these types of materials in-operando or under light or other stimuli to mimic real-world applications is critical.

Q28. Frontier Technologies and Modern Manufacturing

Additive manufacturing and green chemistry are two fields of this Challenge Area currently experiencing rapid expansion and requiring advanced electron microscopy. Green chemistry as applied to the production of ammonia was mentioned above. Additive manufacturing is particularly dependent on electron microscopy, with knowledge of atomic-scale defects and the location of single atoms critical to its research – see for instance, recent work by an Australian-led international team on new titanium alloys for the aerospace industry (Zhu et al. Nature Materials 2022). Accurate location and identification of atoms in 3D, crucial for future research in this area, is currently not possible with present capabilities. Another important research activity relevant to developing sovereign capability for Australia is the fabrication of virus test kits such as for COVID-19.

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

Emerging research directions: • Lithium extraction for use in batteries, solar cells and lightweight alloys • Battery materials • Solar cells • Green catalysis for decarbonising energy-intensive industrial chemical processes. • Improving the recyclability of materials • Sustainable food and beverage processing and packaging • Lightweight structural materials for transportation and the building industry • New materials for communication and sensing Critical infrastructure required: next-generation electron microscopes with: • Ultra-high spatial resolution (picometer scale) in three dimensions AND minimal damage and disturbance to the probed material • Capability to locate “difficult” chemical elements such as lithium at the level of individual atoms. • High temporal resolution and sensitivity to study the evolution of materials and their properties, including under applied stimuli such as light, temperature (furnace to liquid He), force, electrical current. • Ultra-high sensitivity, high dynamic range electron detectors with high time- and energy-resolving capabilities and large pixel arrays.

Q31.

Supporting healthy and thriving communities

Emerging research directions: • Membranes and porous materials for filtering out pollutants from the atmosphere or water. • Sustainable food and beverage processing and packaging • New bio- and medical materials (implants, drug delivery agents, scaffolds, biomolecular sensors, virus test kits) • New materials for communication Critical infrastructure required: next-generation electron microscopes with: • Minimal damage and disturbance to the probed material at highest spatial resolution • Capability to locate “difficult” chemical elements such as lithium at the level of individual atoms. • High temporal resolution and sensitivity to study the evolution of materials and their properties, including under applied stimuli such as light, temperature (furnace to liquid He), force, electrical current. • Ultra-high sensitivity, high dynamic range electron detectors with high time- and energy-resolving capabilities and large pixel arrays.

Q32.

Elevating Aboriginal and Torres Strait Islanders knowledge systems

Q33.

Protecting and restoring Australia’s environment

Emerging research directions: • Membranes and porous materials for filtering out pollutants from the atmosphere or water. • Green catalysis for decarbonising energy-intensive industrial chemical processes. • Improving recyclability of materials • Sustainable food and beverage processing and packaging Critical infrastructure required: next-generation electron microscopes with: • Ultra-high spatial resolution (picometre scale) in three dimensions AND minimal damage and disturbance to the probed material • Capability to locate “difficult” chemical elements such as lithium at the level of individual atoms. • High temporal resolution and sensitivity to study the evolution of materials and their properties, including under applied stimuli such as light, temperature, force, electrical current. • Ultra-high sensitivity, high dynamic range electron detectors with high time- and energy-resolving capabilities and large pixel arrays.

Q34.

Building a secure and resilient nation

Emerging research directions: • Lithium extraction • Battery materials • Solar cells • Green catalysis for decarbonising energy-intensive industrial chemical processes. • Improving the recyclability of materials • Sustainable food and beverage processing and packaging • Membranes and porous materials for filtering out pollutants from the atmosphere or water. • New bio- and medical materials (implants, drug delivery agents, scaffolds, biomolecular sensors, virus test kits) • Lightweight structural materials for transportation and the building industry • Alloys and composites exhibiting ultra-high strength relative to weight, strong corrosion resistance and/or robustness under heavy neutron irradiation • Materials for communication and sensing • Low energy electronics • Quantum computing • Additive manufacturing Critical infrastructure required: next-generation electron microscopes with: • Ultra-high spatial resolution (picometre scale) in three dimensions AND minimal damage and disturbance to the probed material • Capability to locate “difficult” chemical elements such as lithium at the level of individual atoms. • High temporal resolution and sensitivity to study the evolution of materials and their properties, including under applied stimuli such as light, temperature, force, electrical current. • Ultra-high sensitivity, high dynamic range electron detectors with high time- and energy-resolving capabilities and large pixel arrays.

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.

As a major node of NCRIS-funded Microscopy Australia and constituting national infrastructure, the Monash Centre for Electron Microscopy has enabled critical research in ALL the challenge areas and 4 out of 5 priority areas listed above. This research has taken place at the national level, involving cross-national teams, with translation to industry. Key capabilities for driving further advances in those priority areas and beyond must include both nationally significant instrumentation, highly specialist expertise plus an environment providing “supporting/feeder” instrumentation. In more detail: Nationally-significant Instrumentation: 1. Atomic-scale, ultra low-dose imaging, in three dimensions, of delicate materials (essential for nearly all materials). Electron microscopy currently can provide atomic-scale structural information in two dimensions, but routine access to the third will require new technology (fast, sensitive detectors and electronics). This will benefit all fields mentioned above. 2. Atomic-scale, ultra-low dose imaging of light elements such as lithium (essential for characterising materials as diverse as membranes for lithium extraction, solar-cells and ultra-high-strength lightweight alloys for transportation). 3. Single-atom sensitivity for the identification of all chemical elements. This will benefit all fields mentioned above. 4. Atomic-scale imaging of dynamic processes (essential for characterizing the evolution of materials under different conditions). This will require microscopes with much higher vacuum than currently available and significantly faster detectors. This will benefit all fields mentioned above. 5. Ultrahigh energy resolution (<5meV) with atomic spatial resolution for the measurement of materials electronic and optical properties in the microscope, for correlation with structure and chemistry at the atomic scale. This will particularly benefit Challenge Areas 3-8. 6. Atomic-scale characterization of materials at temperatures down to liquid helium, for example for the study of quantum materials and some beam-sensitive materials. This will particularly benefit Challenge Areas 4,6 and 8. 7. Field-free transmission electron microscopy, enabling magnetic materials to be characterized at much greater spatial resolution than currently possible now. This will benefit Challenge Areas 1, 3-8. Some of these capabilities, at least in part, are already available outside of Australia (Instrumentation Capabilities 4, 7). Rapid technological advances in electron microscopy hardware and computational methods are taking place now that offer the prospect of Instrumentation Capabilities 1-3, 5 and 6 becoming a reality within the next 3 to 5 years. This will enable the development of new materials and devices for health, the environment, energy, mineral extraction...etc. Such advances must be enabled at the national infrastructure level so they can be accessed by all Australian researchers and benefit Australian society and industry. Expertise: Without expert staff to run complex cutting-edge instrumentation, such instrumentation cannot be utilised to its full capability, if at all. The “human capability” is as critical as the instrumentation, and it is something that must be developed alongside it, as new technology becomes available and is improved locally. Owing to its complexity, such instrumentation can take several years to generate research outputs. It is therefore essential for expert staff to have sustained tenure, that lasts at least as long as the lifetime of the instrument (typically 10 years or more). Supporting/feeder infrastructure; Nationally-significant instrumentation also needs to be housed within an environment that provides the requisite supporting infrastructure, such as a stable building, specimen preparation equipment, inert specimen transfer and feeder instruments for preliminary or supporting experiments.

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) interacted with or used Australia's NRI?

☐ 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.

This question was not displayed to the respondent.

Q39.

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

This question was not displayed to the respondent.

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.

As mentioned above, new capabilities in instrumentation AND expertise, together, are needed to address current societal challenges. Enhanced capabilities not only enable research progress, but they also lead to the training of Australia's future workforce in advanced technologies. The Monash Centre for Electron Microscopy alone trains over one hundred postgraduate students every year to use electron microscopes hands-on. This is a significant contribution to the workforce critical for Australia to increase its sovereign capability.
