australian and new zealand

synchrotron based science strategic plan

2007–2017

Australian Synchrotron

AUSTRALIAN
SYNCHROTRON
RESEARCH
PROGRAM

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executive summary

This decadal strategic plan for synchrotron-based science focuses on directions in research and the capability development that will be needed to capitalise on those directions. It looks forward to 2017, which will be ten years from the opening of the Australian Synchrotron and 21 years since the launch of the Australian Synchrotron Research Program. The plan will continue to be revisited in coming years.

Planning built on trends noted in four major areas: health and medicine research, Earth systems research, materials and manufacturing, and emerging methodologies. Overall, specific trends were identified in structural biology, medical imaging and therapy, structural genomics, pharmaceuticals, cellular imaging, environmental science, extreme conditions science, geological science, minerals processing, materials science, nano-science, textile sciences, energy science, manufacturing and measurement techniques, including ultra-fast, ultra-sensitive and ultra small scales. Other important trends include the growing demand for remote access to facilities and the continued increase in international collaboration.

The top priority for the Australian Synchrotron community is completion of the initial suite of beamlines to world-class standard. The community also regards it as essential that funding continues to be available to access international synchrotron facilities until Australian Synchrotron beamlines are operational, and thereafter to access synchrotrons overseas for capabilities not available locally. Access to the Australian Synchrotron and international facilities will best be provided within a single framework. Funding is particularly necessary to support travel and subsistence as part of access to facilities.

The Australian Synchrotron has the capacity to host more than 30 beamlines. A plan for evolution at the Australian Synchrotron was developed as part of the decadal planning process, based on user demand, scientific excellence, national priorities, economic impact and instrument excellence. This resulted in three phases of enhancement:

1. In the near term, circular dichroism, combined micro X-ray diffraction and fluorescence, medical imaging and extended-capability X-ray absorption spectroscopy

2. Following that, high energy X-ray diffraction, high-throughput micro computed tomography, a long, high coherence beamline, quick-scanning X-ray absorption spectroscopy and time-resolved reflectometry.

3. Areas that require scoping or emerging were micro lithography, nano lithography, photoemission electron microscopy, resonant inelastic X-ray scattering, small molecule crystallography, a tera hertz beamline, another protein crystallography beamline, a vacuum ultraviolet beamline and X-ray microscopy / scanning transmission X-ray microscopy.

Developments in accelerators, detectors, robotics for remote access and X-ray optics should also be introduced in collaboration with research partners and further skills development undertaken. Industry linkages must also be strengthened.

1. about this plan

The Australian and New Zealand synchrotron community decided in late 2005 to prepare a 10-year strategic plan for synchrotron-based science. Their vision for the plan was as follows:

> *Through the framework set out in this strategic plan, the Australian Synchrotron will become and continue to be a state-of the-art facility and researchers in Australia and New Zealand will be at the forefront in using synchrotrons. The synchrotron community will continually monitor international trends and, as we go forward, we will revise our strategies and ensure access to international facilities that meet our research needs. We will also build collaborative relationships across complementary disciplines and techniques.*

The synchrotron community is keen to show all organisations involved in developing, using and funding synchrotron-based science in Australia and New Zealand a well thought-through strategic plan for the research infrastructure that would best meet emerging needs over the coming decade. It is important for infrastructure and research program planning that users and facility providers establish an agreed direction for the next phase of developments. The exploitation of the full potential of the Australian Synchrotron demands a long-term planning process and sustained funding for the development of new techniques and the continued upgrading of the facility.

The plan will serve as a platform for evaluating and prioritising investments when they are being defined, and for reviewing the benefits that have been obtained from those investments when they are in place.

The plan focuses on directions in science over the coming decade and the capabilities that will be needed to capitalise on those trends. It considers potential new beamlines and other technologies and sets timeframes around them. It examines options that would require investment in infrastructure in Australia and other options based on continued access to overseas synchrotrons.

1.1 Developing the plan

Forecasting trends is an imperfect science, but the community has sought to increase the accuracy of this plan by seeking input from a broad range of organisations and individuals. The process began with the formation of an expert subcommittee on decadal planning that represented a range of users around Australia and in New Zealand as well as the Australian Synchrotron and the Australian Synchrotron Research Program (ASRP, see Appendix 2). They issued a request for submissions in December 2005 to which 40 responses were received (see Appendix 3).

Through April and May 2006 the committee drafted a consultation paper which was published in May 2006. Feedback was received from the Australian Synchrotron Project's National Science Advisory Committee (NSAC), International Scientific Advisory Committee and National Industry Advisory Committee (NIAC), individual researchers, research organisations, scientific and professional societies, and government committees (see Appendix 4). The committee took those responses into account in producing the final plan.

1.2 Reviewing the plan

The plan will continue to be revisited in coming years. The process for review will be determined within the governance and advisory structures of the Australian Synchrotron.

2. national priorities

The decadal planning committee was highly conscious of the need to be transparent and accountable not only to their own community but also to the broader research community and taxpayers of Australia and New Zealand. In that light, they have paid considerable attention to national priorities.

For both Australia and New Zealand, the pursuit of research excellence is a top scientific priority. We don’t want to be doing ‘also ran’ science, as this would not give our industries a competitive advantage nor help our countries to attract and retain the best scientific talent. Maintaining a competitive edge internationally also requires a balance of research, covering pure, basic research, strategic research programs, tactical research, experimental development and short-term problem-solving.

Synchrotron technology contributes to all four of Australia’s National Research Priorities (NRPs), namely:

1. An Environmentally Sustainable Australia
2. Promoting and Maintaining Good Health
3. Frontier Technologies for Building and Transforming Australian Industries
4. Safeguarding Australia

For the New Zealand Government, a top priority is research in health, such as in diabetes and cancer. Having a substantial agricultural basis in the economy, biotechnology is also a high priority, which informs areas such as food and beverages, nutraceuticals and biosecurity. These relate also to other priority areas such as climate change, oceanographic research, sustainable development and biodiversity. Nanotechnology, energy and environment roadmaps have been published.

3. research trends

In identifying trends or directions in science, the synchrotron community is seeking to establish what science needs to be done in our national interest, where our national strengths lie and the important international trends. It is only by being continually aware of international trends and developments that the Australian Synchrotron and local synchrotron users will be able to remain at the forefront of research over the next decade.

A revolution is under way in biology and biotechnology that will escalate in coming years. Moreover, engineering and life sciences are converging. Major advances are appearing in materials science. Meanwhile traditional industries such as agriculture and mining continue to innovate to maintain their competitive advantages. Following are 16 trends in research that the synchrotron community expects to be of significance (noting that the order does not reflect any ranking of importance).

Internationally synchrotron science continues to grow rapidly, including in the size of user communities, the number of facilities and developments in experimental techniques and instrumentation. The trends in Australian synchrotron science cover the spectrum from catching up to the international situation to, in a few disciplines, being at the leading edge of developments.

Examples are:

- In environmental science Australia is experiencing expanding demand for synchrotron techniques to solve problems in areas such as soil science, minerals processing and metals in the environment

- In structural biology Australian users have led the way to the use of ever smaller crystals, and this has driven the design of the undulator-based protein crystallography (PX) and small molecule diffraction beamline at the Australian Synchrotron.

3.1 Health and medicine

Structural biology
Structural biology seeks to understand living systems by characterising the structures of molecules of biological significance, such as proteins, nucleic acids and their complexes. These may form large molecular complexes, which can be studied by PX, the premier technique for probing biomolecular structure; small angle X-ray and neutron scattering (SAXS and SANS); circular dichroism (CD) spectroscopy; X-ray absorption spectroscopy (XAS); micro-Fourier transform infra-red (micro-FTIR) spectroscopy; and micro-probe.

These techniques provide complementary information with varying degrees of detail: PX provides virtually atomic resolution in the crystalline state; SAXS and SANS provide overall shape information in solution; CD probes the percentage of different local structures of proteins in solution; XAS can give precise estimates of metal environments in large molecules; and micro-FTIR and micro-probe can be used to study structure directly in cells and tissues. Structural biology is an integral part of 'rational' drug design programs, where the atomic structure of a target biological molecule is determined to high resolution, and a drug specifically designed using this information. A recent example is the development of anti-parasite vaccines for stock. Increasingly, rational design is being chosen by drug companies and research institutes worldwide as the basis of their drug discovery programs and many new drugs in clinical trials were developed by this route. As noted below in Section 5, Australia had an early success story with the development of Relenza.

The first beamlines on the Australian Synchrotron—most notably PX, SAXS and XAS—largely meet demand for structural biology research for the 20 or so structural biology laboratories currently in research institutes and universities in Australia and New Zealand. In addition, the new OPAL research reactor in Sydney (see Section 5.5) will have world-class facilities for SANS.

Of the number of new techniques that are emerging, one of the most significant is using circular dichroism to analyse the structure of proteins. This is widely practised in the laboratory but is relatively new to synchrotrons. A synchrotron extends the range of CD to higher energies with an enormous increase in the power of the technique when applied to proteins. The utility of these methods is only now being fully appreciated.

Methods traditionally associated with materials science, notably SAXS, have been emerging as major tools in structural biology. This has arisen from a desire to study proteins and other biological macromolecules in an environment that is closer to their native environment, such as in solution or as they interact with other molecules. It is expected that the demand for such tools will increase significantly in the coming years.

There are a significant number of membrane proteins that typically cannot be crystallised but are the targets of the great majority of current drugs. This is a major focus of development overseas of fourth generation sources (in particular, X-ray free-electron lasers – XFELs) and is being pursued in many laboratories with a view to studying structures with single molecule samples. Australia has excellent expertise in all aspects of this work and has put together a multi-disciplinary team under the Australian Research Council (ARC) Centre of Excellence for Coherent X-ray Science (CXS).

Medical imaging and therapy

Synchrotron techniques are attractive for medical imaging as they offer greatly reduced X-ray dose, massively enhanced contrast and can even differentiate tissue types. The fine structure of organs can be examined and disease states can be detected and tracked. Recently it has even proved possible to track therapeutically introduced cells in vivo. Current fields of great interest within Australia include neonatal lung imaging, examining the deformation of teeth, and imaging airway surfaces for assessment of cystic fibrosis disease. Synchrotrons are also multi-modal, allowing a problem to be analysed in various ways, which means a number of imaging methods can be used in a ‘one stop shop’ approach.

Synchrotrons provide a unique capability for the investigation of advanced radiotherapy techniques. Several new modalities are being pursued and they appear to offer tremendous potential for treating tumour types that are currently considered untreatable by conventional methods.

Australia has world-leading skills in medical research and strong expertise in advanced X-ray imaging techniques and fundamental X-ray physics. Australian groups are at the forefront of new imaging techniques such as phase contrast and coherence-based methods, and have joined forces in the ARC Centre of Excellence for CXS. Our region is underdeveloped in medical imaging research. The importance of this field has been underlined by the creation of the Cooperative Research Centre (CRC) in Biomedical Imaging Development.

Structural genomics

Structural genomics is already a significant international effort, with large exercises under way in a number of countries. Set-up costs in this area are very high. Australia has had very little impact in this area due to the absence of high-throughput PX synchrotron facilities, which are essential for structural genomics. It is also possible to envisage the development of high-throughput techniques for XAS to characterise the entire complement of metal active sites in a proteome.

For these reasons the genomes being investigated in this area have been dictated by overseas countries and consortia. The Australian Synchrotron provides an opportunity to explore genomes of interest particularly to our national and economic interests, such as those involving pathogens of particular medical or agricultural relevance.

Meanwhile, new opportunities exist in niche areas that target particular functional aspects of genomics. Examples of projects in early stages include gene discovery in environmental organisms and macrophage structural genomics.

Pharmaceuticals

Synchrotron-based research plays a major role in the design, characterisation, mode of action, and safety of metal-containing drugs, and Australia is a world leader in this area. Bulk XAS and single cell and tissue studies with X-ray and FTIR micro-probes are providing unprecedented information on the biodistributions, biotransformation, efficacy and safety of new and existing drugs and are revolutionising drug design in certain areas.

In addition, synchrotrons can be used to characterise drugs within pharmaceutical formulations and their distribution within formulations using X-ray and FTIR techniques. Australia needs access to high-throughput methods for drug discovery and rapid diagnostics and to increase its capabilities in drug design. It should be noted that veterinary pharmaceuticals are a particularly large market for Australian and New Zealand industry.

Cellular imaging
In imaging the whole cell a researcher can look at cellular structure at very high resolution. Cellular imaging can take many forms, from the production of high resolution elemental maps using scanning probe techniques, an area in which Australia has world-leading scientists, through to mapping molecular structures using scanning infra-red (IR) spectroscopy, to imaging cellular architecture using high resolution soft X-ray microscopy.

The committee's survey of potential users demonstrated that high resolution soft X-ray microscopy is an area for which there is a high potential demand in the Australian community and, although it is an area that has many potential applications, it is not one in which Australia currently has high level expertise. The ability to meet the demand for soft X-ray microscopy will require a mix of access to overseas facilities and strategic investment at the Australian Synchrotron.

Whole cell imaging with coherent X-rays is more challenging, is an area of intense international development and is closely related to the single molecule imaging effort discussed above.

3.2 Earth systems

Environmental science
Growing concern about environmental issues, including climate change, salinity and Antarctic science, opens opportunities for synchrotron science to be applied in bioremediation and environmental biogeochemistry. Synchrotron techniques offer the potential to advance our understanding of the environmental behaviour of inorganic contaminants and major elements. This will underpin development of integrated modelling approaches to determine the implications of system perturbation on trace element/mineral transport and transformation due to anthropogenic activities or natural environmental change. The outcomes will be seen in risk assessment protocols, management options, land-use policies and strategies for exploration for concealed mineral deposits. Synchrotron X-ray techniques provide the unique capability to measure distribution and chemistry of key elements in situ, i.e. in the original soil, plant or water environment. This is the basis of the relatively new field of molecular environmental science. For example, the chemical state of metals in environmental systems determines their toxicity and mobility, which are the key factors determining their environmental impact.

The use of synchrotron techniques to assess the fate and behaviour of organic contaminants is an emerging area of research. There is the possibility, especially through the microspectroscopy, combined microdiffraction and fluorescence, XAS and infra-red spectroscopy beamlines at the Australian Synchrotron, to position Australia at the forefront of research in this area. This area of synchrotron application is growing rapidly in Australia.

Extreme conditions science

Experiments at extreme temperatures (up to 5000 Kelvin, namely Earth inner-core temperature), pressure (up to 5 Mbar) and magnetic field (up to 50 Tesla, constant and pulsed) are now feasible or within reach. The combination of various synchrotron-based techniques can provide valuable information on the structural, dynamic, electronic and magnetic properties of materials under previously unexplored conditions, relevant in a large range of scientific disciplines, from biology to cosmology. This is also discussed below in the specific context of geological science minerals processing. In these cases the sample volume is very small. For example, a typical diamond anvil high-pressure cell will have sample sizes in the tens of micron range. High brightness synchrotron sources are, therefore, necessary.

Geological science

Traditional empirical exploration methods are becoming less effective and consequently more costly as exploration is forced to move to more deeply weathered terrains. In order to redress this decline, significant investment has been made in research to increase our understanding of ore-forming processes and metal dispersion during weathering. However, progress is limited by a lack of fundamental understanding of the behaviour of metals in complex chemical systems. Generation of accurate, predictive 3D models of the Earth's crust based on integrated geophysical and geochemical datasets is the aim of the next generation of truly predictive mineral exploration. However, predictive reactive transport models fundamentally depend on thermodynamic data and models relating to the mineral and chemical species present in ore systems. Synchrotron techniques are having a significant impact in this field.

The ability to fully characterise metal speciation and distribution from deeply buried hypogene ore, the regolith (deeply weathered rocks) through to the vegetation at the surface is of fundamental importance to mineral exploration, mineral processing and understanding environmental degradation and its remediation.

Our current level of understanding of metal transport from hypogene ore to the surface has largely arisen from relatively bulk studies. However, processes at the nano- to micro-scale are key in this regard. Synchrotron techniques such as microspectroscopy, and new techniques that combine microdiffraction and fluorescence simultaneously for mapping trace composition and mineralogy, have enormous potential in this research.

Experimental studies of solubility of metals at high temperature and pressure are also advancing. Using new techniques, an experimental charge can be monitored during the experiment and direct information on species obtained. This has great potential to change paradigms on the behaviour of metals in the Earth's crust and ultimately to lead to better understanding of the chemical processes of metal deposit formation and accelerated discovery of new resources.

Minerals processing

Experimental methods for the in-situ study of natural samples and systems at extreme pressures and temperatures are undergoing rapid evolution, fuelled by the advent of high-intensity synchrotron sources and advances in detection technology.

Extremes of pressure, temperature and composition are found in mineral processing plants, during ore formation in the Earth's crust, in geothermal wells and plants, and in terrestrial and aquatic environments affected by human intervention. Advancement of knowledge of processes under these conditions demands a molecular understanding of key biogeochemical processes in complex systems at low temperatures and at the key interfaces between different phases and fluids within these systems.

An understanding of metal behaviour under frontier chemical and physical conditions is essential to predict system behaviour at the macro-scale in a number of research fields such as ore genesis, mineral exploration and processing, ecotoxicology, environmental management and risk assessment. Being able to predict the behaviour of these systems will improve predictive mineral exploration strategies; increase efficiency of mineral and metallurgical processing; improve modelling of geothermal energy and geosequestration; and improve understanding of metal mobility and toxicity in salinity-affected landscapes, leading to more efficient remediation.

In many cases, processes used for metal extraction by the minerals industry are optimised through measurement of bulk chemistry before and/or after reaction rather than through a specific knowledge of the materials involved in the process. However, any improvement in extraction efficiencies requires detailed understanding of the chemical and mineralogical changes taking place during processing. To obtain such understanding, measurements must be conducted under conditions that emulate the 'real' operating conditions in the mineral processing plant. The technical challenge in deriving this information will be to safely reproduce the sample environments experienced in real systems within the synchrotron-based instruments.

Significant developments in extreme conditions science, geological science and minerals processing will have major impacts on the Australian economy, given the importance of the mining and minerals sector. This community to date has not been strongly engaged in using synchrotrons.

3.3 Materials and manufacturing

Materials science

Advanced materials and engineering materials are expected to change significantly in the coming decade. For example, the study of materials at the mesoscale has applications related to self-assembly, nano-materials and surface properties. In-situ time-resolved studies of dynamic processes in materials will need and benefit from intense sources of hard X-rays, such as the use of very intense white/pink beams at synchrotrons and ultra-short pulsed sources such as are expected from FELs. These new applications of time resolved diffraction and spectroscopy techniques will enable a wide range of study of materials processes.

Identifying new types of advanced materials for manufacturing is a hot area of science with considerable worldwide competition. Success will rely heavily on understanding of the electronic, chemical, structural and physical properties of these materials, at atomic, nano-, micro- and macro-scales.

Nanotechnology is an area of increasing interest internationally. The opportunity exists to exploit the conjunction of Australian leadership in nanofabrication and X-ray imaging. Nanocomposites, bionanocomposites and nano-structured thin films are also areas of potential. In particular, efforts will be directed to development of biocomposites and bionanocomposites from renewable resources to achieve sustainability in industrial applications. Research will also be directed towards smart and self-healing nanomaterials with unique sensing and controlled regenerative growth mechanisms, with the ultimate goal of achieving 'cradle to grave' ecologically sustainable ecomaterials. Advances in the development of new materials based on advances in nanotechnology depend on detailed understanding of structural and chemical characteristics of the material. Such characterisation is best performed using synchrotron methods, and many Australian groups are world leaders in these techniques.

The analysis of magnetic materials is an important branch of materials science, and very active overseas. While this is not presently an active area of research in Australia, the new capabilities offered by the OPAL research reactor (see Section 5.5) and the Australian Synchrotron for analysing magnetic materials can be expected to stimulate increased activity in this area.

Textile science

Vibrational spectroscopy and SAXS will play a significant role in fundamental fibre research as well as in extending our understanding of the effects of both chemical and physical processing of textile fibres. Information can be obtained on chemical composition and distribution, molecular conformation and stress–strain relationships, to name a few. Bi-component fibres and inter-fibre bonding are of particular interest.

Research on pure single nanotube and nanotube yarns would entail study of crystallinity and fibre packing and interaction changes under a range of applied stress and temperature conditions. Use of environmental sample chambers to control environmental conditions, as well as enabling the in-situ treatment of fibres, will also play an important role in much of the envisioned research.

Ultraviolet (UV) surface treatments can be a highly cost-effective means of specifically modifying the surface properties of polymer films and fibre composites, including textiles. Altering such properties as wettability and surface energy can improve commercial performance. UV treatments have also been used to modify the surface properties of textile fabrics. To assess the degree of UV photomodification of materials requires an understanding of their spectral sensitivity, usually in the form of an action spectrum.

Use of monochromatic, high-intensity synchrotron radiation in the visible / UV region (600–120 nm, 2–10 eV) would provide action spectra for the degree of surface modification at different wavelengths very rapidly and the dose of radiation applied to each sample at each wavelength would be highly accurate. This would identify the optimum wavelength necessary for surface modification of a range of polymers and biopolymers, allowing the most appropriate choice of source for any commercial application to be made.

The effects of monochromatic synchrotron irradiation on material properties, such as photoyellowing and photobleaching (colour), mechanical strength, elasticity and abrasion resistance would also be very valuable since samples could be exposed to a large number of different wavelengths and high doses very rapidly.

Energy science

Synchrotrons support the development of new energy technology for hydrogen storage, post-combustion capture of CO_2, solar energy technologies and Hot Dry Rock geothermal energy. For example, to be able to obtain accurate structural data on a range of new inorganic / organic materials and then use in-situ techniques to determine adsorption sites of gases within these structures, would be of enormous benefit in designing new materials for hydrogen storage and post-combustion capture of CO_2.

Other potential application areas are in the development of membranes for gas separation, new materials for hot gas cleanup technologies, characterisation of fine airborne particulates and determination of elemental behaviour in energy waste products, such as fly ash, to provide quantitative data for the prediction of possible environmental consequences arising from proposed disposal or utilisation options.

Manufacturing and nanofabrication

The trend in miniaturisation of components and systems is producing an amazing number of applications in diverse fields of science and technology: the so-called nanotechnology revolution. Synchrotron-based X-ray lithography, also called nanolithography, is an area of science in itself as well as an enabling technology. It has demonstrated its ability to successfully replicate patterns with spatial resolution at the 40 nm level. Challenges in this field are the attainment of finer features, the ability to carve a wide range of 3D structures and the ability to combine these with control of materials properties. Nanolithography techniques offer the potential for the creation of new devices and applications in fields spanning engineering to medicine (e.g. nanophotonics, bio-sensors, guided self-assembly, new diffractive optics, surface templating, tissue scaffolds and microfluidics).

3.4 Emerging methodologies

Ultra-fast science

Ultra-fast science, where measurements are performed on sub-nano and even sub-picosecond timescales, enables the study of physical, chemical and biological processes as they happen. This is a major emerging trend and Australia has a significant community working with lasers, but there has been little ultra-fast X-ray research in Australia.

Ultra-fast science enables the study of physical, chemical and biological processes as they happen and has largely been the preserve of ultra-fast laser science. However, synchrotron and laser science are converging, with the methods developed by laser physicists being transferred to innovative uses of synchrotron facilities. With its existing laser expertise, Australia is in an excellent position to be a major contributor to the development of ultra-fast probing of, for example, processes in the life sciences. Such a convergence must be nurtured through interdisciplinary collaborations between universities, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and other government bodies, such as through the new ARC Centre of Excellence for CXS. Ultra-fast time-resolved facilities for sub-nanosecond pump-probe spectroscopy are also ideal to probe correlated electron systems, superconductivity and details of chemical reaction dynamics.

Processes can be studied in many time domains, such as seconds and minutes for some industrial and environmental processes and nano- to pico- and, for some emerging soft X-ray sources, even atto-second probing of chemical and biological processes. Special techniques can record a whole spectrum or X-ray diffraction pattern simultaneously, such as energy dispersive spectroscopy, SAXS with fast detection and high beam intensity, speeds of nano/picoseconds for some chemical dynamics or using light from a single bunch from a third-generation synchrotron such as the Australian Synchrotron.

FEL sources that produce pulses less than a picosecond in width and operate in the vacuum ultraviolet (VUV) and X-ray ranges are in development overseas to enable sub-picosecond measurement of fundamental dynamics in a broad range of physical situations.

Measurement technique trends

The major international instrumentation and measurement trends are towards ultra-fast, ultra-sensitive and ultra-small measurements.

‘Ultra fast’ is driving innovation in synchrotron beam-optics techniques to produce short (~1 picosecond) pulses and integration of laser pump-probe techniques in spectroscopy and diffraction beamlines to probe atomic and molecular dynamics.

‘Ultra sensitive’ drives both beamline and focusing optics design as well as the emergence of high solid-angle spectroscopy detector strategies.

‘Ultra small’ pushes spatial resolution of almost all techniques, with a goal of less than 10 nm resolution for a number of X-ray imaging techniques.

The world’s three large, high-energy facilities—namely the Advanced Photon Source (APS) in the USA, the European Synchrotron Research Facility (ESRF) and SPring8 in Japan—are all considering significant upgrades driven by these three trends.

3.5 Industry's changing needs

The Australian Synchrotron Project's National Industry Advisory Committee (NIAC) provides guidance on engagement with industry. NIAC sees a key role for the Australian Synchrotron in driving the growth of knowledge-based industries in Australia, especially through the development of 'products of the future'. In particular, NIAC regards flexibility in technical capabilities as essential, together with attention to throughput and efficiency, to allow for experiments that are useful for industrial applications.

Industry is increasingly outsourcing its research and development (R&D) requirements to universities and other public-sector research organisations, rather than conducting its own experiments. This changes the balance of research being undertaken, because industry primarily wants answers to questions.
A group of private research providers is also active, mainly undertaking contracts to resolve industry problems. The shift from conducting experiments to undertaking measurement, which was noted above, relates to this emphasis on solutions to problems. It is, therefore, necessary that the synchrotron community can support this emerging emphasis on measurement, as part of ensuring that industry can take full advantage of synchrotron capabilities in coming years.

4. emerging capabilities

Developments in synchrotron science have been driven by improvements in the source (e.g. higher brightness third-generation storage rings), beamline optics (e.g. high heat load monochromators and micro-focus optics) and detectors. Investment in these areas has roughly come in this order, with detectors lagging behind.

Specific proposals regarding accelerators, optics, detectors and methods are explored in Section 6.3.

4.1 Accelerator development

Pulse compression and pump-probe experiments involve management of the length of the pulse of X-rays from the synchrotron so as to allow the probing of shorter timescales. The precise coincidence of laser pulses and X-ray pulses—so called pump-probe methods—will probe atomic and molecular dynamics and intermediate states of systems to also open up exciting new areas of science. There is potential for local researchers to capture international leadership in this area.

Other new accelerator capabilities that are anticipated to become significant over the next 10 years include:

- Coherent control, as a high level of control of the beam properties will allow beams of varying states of coherence to be created

- Laser slicing, that is, the use of short laser pulses to select out very short sections of an electron beam bunch and generate extremely short X-ray pulses, of the order of 100 femtoseconds

- Top-up mode, by which the electron beam is replenished essentially continuously, which has a major benefit in many aspects of beam quality and which the Australian Synchrotron should implement

- Development of laser-plasma acceleration techniques; huge accelerating gradients of ~10 MeV/mm being theoretically possible. Such accelerators could produce very short pulses of highly coherent radiation

- Insertion devices, as the rapid development of the capabilities of synchrotrons has arisen from ongoing development of insertion devices that enhance the output. This will be an ongoing process involving diverse fields (e.g. accelerator physics and superconducting and magnetic materials science)

- Lattice upgrade, to increase brilliance. The accelerator will be subject to ongoing development and upgrades. There will no doubt be opportunities to increase the brilliance of the synchrotron by modifying its overall architecture—its lattice.

In some of these areas, such as coherent control and insertion devices, the appropriate response in the near term might be only to maintain a watching brief.

The synchrotron community will also continue to monitor developments in fourth generation sources, which are rapidly emerging and will enable scientists to probe structures on unprecedented timescales and image with unprecedented resolution. Fourth generation sources include free electron lasers covering the spectrum from the infra-red to hard X-rays, and energy recovery Linacs. While most of these developments require very high levels of investment (particularly X-ray FELs), there are potential niches for Australia, such as an IR ultra-short (~100 femtosecond) pulse FEL using superconducting accelerator technology. This would enable probing of protein function and it could be accommodated on the Australian Synchrotron site.

Compact, single-purpose synchrotron machines are also being developed around the world. These would be used, for example, to conduct protein crystallography research, or undertake medical imaging, or for micro-circuit lithography or micro-testing. They are designed to have one dedicated beamline and to perform one experiment at a time. Although often described as 'table top' or 'desk top' machines, the full systems are, in fact, larger than this description implies. Compact synchrotrons are expected to have little impact on demand for synchrotron beamtime for at least 15 years. Moreover, many of the perceived benefits can also be gained by using e-Research and remote access networks to undertake research on larger, comprehensively equipped synchrotrons (see Section 4.5).

4.2 Optics

Many advances in beamline technology, and consequently in the range and quality of scientific applications, continue to be driven by advances in optics. Optics developments over the preceding decade have encompassed improved performance from existing optics such as mirrors, increasing use of multilayer coatings and the development of new X-ray optical elements such as refractive lenses, and this trend is forecast to continue over the coming decade. These developments will continue to be driven by the demands of the high power and brightness of the third generation sources and by increasing performance required by experiments.

Key drivers are:

- The push for higher spatial resolution. Current micro-focus optics are still far from theoretical focusing, but a number of programs are pushing towards this with goals of 10 nm focal spots and beyond.

- The need to conserve the brightness and coherence of the current third-generation sources, and at the same time reduce unwanted effects of the source coherence such as spatial inhomogeneities. This is pushing the development of more accurate mirror figuring/polishing technologies, and of new designs such as piezo "bimorph" mirrors that can actively alter their figure.

- The advent of next generation sources. It is possible that the combination of high power, brightness and coherence promised by free electron lasers will lead to fewer or no optical elements being employed in some cases, but many applications will require focusing and monochromatising optics. The challenge of taking full advantage of the performance of these sources will drive improvements in all aspects of experiments, but particularly in optics and detectors.

The manufacture of grazing-incidence X-ray mirrors is currently dominated by a few specialist companies, which are both leading and taking up new developments. The CSIRO Centre for Precision Optics in Sydney has expertise in this area, but aside from this there is limited opportunity or necessity for Australia to play a major role in development of these “conventional” optical devices. However, Australia does have a good track record in conceiving and developing novel optics, for example the “Lobster Eye” micro-machined optics, and very high energy resolution crystal optics. Both of these projects were developed by Melbourne-based groups, so there is an opportunity to combine with the Australian Synchrotron staff and the increasing Australian activities in coherence-based research and form a real critical mass to work on niche novel optics development.

It is important for the development of the Australian Synchrotron and its user community that Australia is engaged with the leading research overseas, and supports world-class local expertise and facilities.

4.3 Detectors

It is generally recognised that there are large gains in capability to be had from new detector developments, and indeed this is an active area internationally. Improvements are needed, and are being realised, in all key performance attributes of X-ray detectors including: dynamic range; energy and spatial resolution; count rate limits and readout time. Detectors have long been the ‘weak link’ in the synchrotron experimental chain. The development of detectors has lagged behind the development of other aspects of synchrotron-related technologies. It is essential to correctly orient the underlying funding priorities to advance detector development to ensure that maximum throughput and data quality is extracted from beamlines.

A number of new collaborations, including CSIRO, the CRC for Biomedical Imaging Development and the University of Melbourne, are intending to inject significant impetus into this area.

Monash University has attracted a very strong research team, many from the distinguished group at the Daresbury Laboratory in the UK. Developments are progressing in both advanced imaging and spectroscopic detectors that are tailored to be suitable for the Australian Synchrotron. Fields in which these developments are set to have a major impact include microanalysis and chemical-state imaging, protein crystallography, X-ray imaging, powder diffraction and small angle scattering.

4.4 Methods

As the technology of synchrotron facilities, sources, optics, detectors etc, improves, new experimental methodologies are continually developed. A number feature in section 6, for example high-throughput micro-computerised tomography (CT), resonant inelastic scattering, tomographic energy-dispersive diffraction imaging (TEDDI) and tera-hertz (THz) techniques. In particular the range of imaging techniques is growing rapidly.

Phase-contrast imaging is emerging as a critically important imaging method using synchrotrons, and Australia has world-leading expertise in this area. The input from the community repeatedly identified this as an important area and we must ensure that the Australian Synchrotron uses its expertise to implement world-leading phase-contrast imaging facilities.

Many, if not most, molecules of biological interest are not amenable to imaging by conventional crystallographic methods. One potential solution to this problem is to use diffraction from fourth-generation sources. Australia must have access to these facilities if our scientists and industries are to benefit from the information yielded by these techniques.

As experimental methods develop, there must be a parallel development in sample handling. This is a rapidly emerging area and we must ensure that Australia remains at the forefront of these developments.

In addition, there is an emerging trend to combine techniques on some beamlines, i.e. to apply multiple techniques simultaneously or sequentially on the same sample at a single beamline. In some cases these are becoming standard and are reflected in Australian Synchrotron beamline designs. For example, small and wide-angle scattering will be simultaneously available, and the microspectroscopy beamline combines fluorescence mapping and micro absorption spectroscopy. Similarly, the combined microdiffraction and fluorescence beamline will provide simultaneous structural and chemical imaging data. There is also a clear trend to provide non-synchrotron analytical techniques in combination with synchrotron beamlines. In some cases this can be in-situ, for example light scattering in the sample station. Equally important is the provision of off-line analytical capability at the synchrotron facility such as IR and UV-vis spectrometers.

Combined techniques should not be confused with multipurpose beamlines, i.e. beamlines whose configuration can be changed to perform a range of different techniques on unrelated samples. It is inevitably impossible for a beamline to be able to deliver more than one technique at a world-leading level and so there is a definite international trend away from such beamlines, towards beamlines dedicated and optimised for a single technique or a small group of related techniques. The ASRP has seen this first-hand with the challenges that the APS has faced in managing its Collaborative Access Team system, where a large number of multipurpose beamlines were built. The Australian Synchrotron has taken careful note of this trend and the initial suite of beamlines is largely dedicated to single techniques. The committee recommends that this practice continue.

4.5 Access

eResearch has emerged as an increasingly important trend across all research areas in recent years, and will become an intrinsic aspect of research over the coming decade. It will enhance and stimulate collaborative research and will be indispensable for cost-effective access to major facilities. Elements such as virtual laboratories and other collaboration environments, high capacity and high performance networks, databases and database services, remote access to synchrotron beamlines, high performance computing and grid computing (for automated structure determination) and mass data storage will be required in the near future for scientific experimentation and communication.

Researchers are especially seeking remote access to facilities. It is not only a matter of linking to a facility from a university or research institute, but also of the connections between facilities, such as between the Australian Synchrotron and the new OPAL research reactor that has opened in 2007 in Sydney (see Section 5.5).

External 'virtual' laboratories are also of increasing interest. These enable researchers to participate in an experiment remotely and allow 'off-line' analysis of data.

International collaboration is continuing to grow in volume and importance. This often involves Australian and New Zealander researchers travelling to other facilities to work with collaborators there, reinforcing the need for programs to support travel and access to overseas facilities (see Section 6.2). In this regard, it is notable that international collaborations have been a key to New Zealand and non-ASRP synchrotron usage over the past decade.

There is potential for the Australian Synchrotron to work with complementary facilities (see Section 5.5) to improve researchers' access to experimental data through, for example, common data archiving for related techniques such as diffractometry.

4.6 Skills and expertise

A trend is anticipated towards the use of synchrotron facilities by non-experts. For example, few of the younger protein crystallographers have any formal crystallographic training or experience and X-ray microscopy is being increasingly taken up by researchers with no synchrotron experience (e.g. in environmental science and biological research). Consequently, facilities will experience increasing reliance on scientific as well as technical expertise provided at the beamline and a need for highly automated, integrated procedures. This trend provides significant stimulus for universities and training institutions to take a leadership role in providing appropriate courses and training for this next generation of experts in the development and application of synchrotrons.

The ARC recognised this in funding the Molecular and Materials Structure Network. In the past, programs such as those run by this network, the ASRP and Australian National University (ANU) summer schools have collaborated to provide training courses in a range of synchrotron techniques. The Australian Synchrotron should continue such collaborations to address major skills shortages.

The development of skills needed going forward is discussed in Section 6.4.

5. our strengths

Australia and New Zealand have built up expertise in synchrotron use over the past decade to the extent that there are now more than 400 users in Australia and about 13 active user groups in New Zealand. The improved access and proximity offered by the Australian Synchrotron will enable that number to be substantially increased.

The Australian Synchrotron Research Program was established in 1996 under the first round of the Australian Government's Major National Research Facilities (MNRF) program to provide Australian scientists with access to state-of-the-art synchrotron radiation research capabilities at overseas synchrotron facilities. Australia is recognised for its strengths in using synchrotrons in, for example, materials science, medicine, biology, geoscience and minerals and environmental research. Australia also has a local detector development community, established expertise in spectroscopy and a particularly strong, world-leading X-ray phase-contrast imaging community.

New Zealand scientists currently use nine overseas synchrotron facilities. Their work is broad-based in discipline and technique, covering the major areas of strategic importance in Government science policy such as biotechnology, materials, nanotechnology and information science.

For New Zealand users, requests for synchrotron beamtime have been based on personal contacts and international collaborations, and thus have been limited to relatively senior scientists who have such contacts.

The benefits to date of synchrotron use by Australians and New Zealanders have been spread across their economies and societies.

For example:

- The development of the Australian anti-influenza drug Relenza was based on the crystal structure of neuraminidase solved by Professor Peter Colman and Dr Jose Varghese of CSIRO from data collected at a synchrotron

- New drugs utilising copper and zinc are emerging from collaborative research undertaken by Professors Peter Lay and Trevor Hambley and Associate Professor Brendan Kennedy. Medical Therapies Ltd was established to take these drugs into the human markets for the treatment of inflammation, pain and cancer.

- Synchrotron-based research by Professor Keith Nugent, ARC Federation Fellow in the School of Physics at the University of Melbourne, is the basis for a Victorian company, IATIA, which is now traded on the Australian Stock Exchange and resulted in Professor Nugent being awarded the 2004 Victoria Prize

- Synchrotron medical imaging and detector development work by Professor Rob Lewis and colleagues of Monash University has attracted US technology giants to invest in and share their technologies with the CRC for Biomedical Imaging Development

- A new silk-like fibre made from wool, called Optim, resulted from more than 10 years of development by CSIRO and the Woolmark Company using synchrotron analysis. Optim is arguably the most significant breakthrough in wool technology since the 1960s.

5.1 Australian Synchrotron

The Australian Synchrotron is a 3GeV third-generation synchrotron that is being constructed in Melbourne. It will open in 2007. The initial suite of beamlines was chosen as a result of the National Science Case (NSC) prepared by the Australian Synchrotron's National Science Advisory Committee. The NSC set out 13 beamlines, of which nine form the initial suite, being those that were considered essential to be available or under construction at the commissioning of the synchrotron. This suite provides a comprehensive range of techniques that will meet most current scientific, medical and industrial research needs.

The first nine beamlines being implemented at the Australian Synchrotron are as follows (following the numbering in the NSC):

Beamline 1.	High-throughput protein crystallography
Beamline 2.	Protein microcrystal and small molecule diffraction
Beamline 3.	Powder diffraction
Beamline 4.	Small and wide angle X-ray scattering
Beamline 5.	X-ray absorption spectroscopy
Beamline 6.	Soft X-ray spectroscopy, with X-ray photoelectron spectroscopy
Beamline 8.	Infrared spectroscopy
Beamline 9.	Microspectroscopy
Beamline 10.	Imaging and medical therapy.

Construction of the Australian Synchrotron machine and buildings is being funded by the Victorian Government. In an unprecedented level of co-investment, a number of universities, research institutions and Australian State governments as well as the New Zealand Government are providing additional investment in the initial suite of beamlines, making them Foundation Investors in the Australian Synchrotron Company.

5.2 Australian Synchrotron Research Program

The ASRP is managed by the Australian Nuclear Science and Technology Organisation (ANSTO). Its members are: ANSTO, ANU, CSIRO, Curtin University of Technology, Monash University, University of Melbourne, University of New South Wales (NSW), University of Newcastle, University of Queensland, University of South Australia, University of Sydney, University of Western Australia, the State of NSW and the State of Victoria. The University of Canberra is an Associate Member.

As well as its Director, the ASRP team comprises six staff scientists who are based at ASRP synchrotrons overseas. The ASRP provides access to three leading overseas synchrotron laboratories:

- The Australian National Beamline Facility (ANBF) at the Photon Factory, Tsukuba Science City, Japan

- The Advanced Photon Source at the Argonne National Laboratory, Chicago, USA

- The National Synchrotron Radiation Research Center (NSRRC) in Hsinchu, Taiwan

More detail on these facilities is provided in Appendix 5.

5.3 Other international access

Australians also access other major synchrotrons in the USA, Europe and Asia via the Access to Major Research Facilities Program (AMRFP), which is funded through the Australian Government's International Science Linkages program. The AMRFP supports travel in order to access a major research facility not available in Australia—that is, experiments that cannot be undertaken in Australia—or to attend overseas strategic planning meetings to secure access to a major research facility. However, it cannot meet the full demand on its funding.

5.4 International cooperation

The new Asia–Oceania Forum (AOF) for Synchrotron Radiation Research held its first scientific meeting in November 2006. This Forum has a strong focus on users. Its formation reflects the considerable momentum towards regional collaboration. The AOF has potential to be the vehicle for sharing beamlines, staff exchanges and bringing the regional user community closer together. By taking a leading role in the AOF, the ASRP and the Australian Synchrotron can highlight and reinforce our areas of regional leadership.

In addition, the Australian Synchrotron Project has established memoranda of understanding (MoUs) with a number of synchrotrons around the world and a number of MoUs and agreements also underpin the ASRP's relationships (see Appendix 6). The synchrotron community believes that these MoUs, and those signed in the future, should support genuine cooperation among regional facilities. Greater collaboration should also be fostered with users in Southern Africa, Asia and Pacific Rim nations. Student exchanges in particular are the foundation for lifelong relationships.

Regional and international relationships will supplement the knowledge held by the Australian and New Zealand synchrotron communities, support continued access to facilities in other countries, encourage international users to Australia and are the platform for potential co-investment in facilities at the Australian Synchrotron. The ASRP's investments in the ANBF and the NSRRC, and the NSRRC's investments at SPring8 in Japan—to which Australians have access via the ASRP—demonstrate the operation and benefits of such co-investment. In fact, the ASRP has been a model for other facilities in the region.

The growth in such relationships and the potential offered by the AOF reinforces the need for significant investment in eResearch, not only for users within Australia and New Zealand but also for users accessing the Australian Synchrotron from other countries.

5.5 Complementary Australian facilities

Neutron scattering is highly complementary with synchrotron radiation. X-rays scatter from electrons and consequently do not precisely and accurately locate the positions of nuclei and hence atomic positions, whereas neutron scattering pinpoints atomic positions, especially for the lightest atoms. Australia's only neutron scattering facility is ANSTO's research reactor. An obsolete reactor has been replaced by the OPAL reactor in 2007. OPAL will be one of the top reactors of its type in the world. Australian Synchrotron beamlines complement OPAL beamlines, especially due to the common foundation in Australia's strengths and contemporaneous trends. Such complementarity increases the attractiveness of these Australian facilities to researchers overseas, expands the scope of research undertaken in Australia and furthers outreach to industry and potential new users of these capabilities.

ANSTO, 36 Australian universities and a consortium of New Zealand universities and research institutions form the Australian Institute of Nuclear Science and Engineering (AINSE), which funds access to ANSTO's facilities. AINSE funds travel and access costs for member institutions.

Some synchrotron users also use microscopy and microanalysis facilities located in Australian universities and science and technology organisations.

6. making our future a reality

We must make choices and set priorities about what facilities will yield the greatest benefits and when they should be implemented. Benefits include the economic, industrial, environmental and social rewards flowing from leading science and innovation. The choices include new instruments on the Australian Synchrotron, refurbishments, and how we might best continue to use facilities in other countries. It is vital that we maintain the science base of the Australian Synchrotron while seeking to take leading international positions in emerging areas of science. The choices we make will build on the strengths that we now have and the opportunities for innovation that are emerging in new scientific directions and synchrotron techniques.

Specific scientific goals need certain types of instruments. But to take advantage of synchrotron instrumentation we must be able to access it effectively, whether it is in Melbourne or overseas, and we need to ensure that we are developing sufficient and appropriate skills for the future.

The Australian Synchrotron in 2017 will not look like it does in 2007. Synchrotrons must be continually upgraded and evolve in their capabilities, including new, refurbished and extended beamlines and other capabilities such as accelerators, optics and detectors. This is essential to ensure that their research outcomes continue to be excellent on a global scale and contribute to internationally competitive product innovations.

Improvements in beamlines aim to improve performance on many fronts, such as X-ray intensity and/or stability, time, energy, momentum or spatial resolution, sensitivity, throughput, detector performance and user-friendliness of control software.

6.1 Factors in assessment

The development of the decadal plan has provided an opportunity for reassessing the beamlines that were proposed in the National Science Case in 2003. The process has been forward-looking: based on our ability to respond to trends anticipated over the coming 10 years and the potential benefits.

The Expert Subcommittee on Decadal Planning analysed submissions it received to identify the capabilities that the synchrotron community especially sought and related these to the trends in research and capabilities that hold particular promise, as set out in Sections 3 and 4. The committee then identified five factors to be considered in assessing how soon new capabilities should be introduced, namely:

1. User demand or need (30%): This was based on the committee's assessment of the size of the user community once such a facility is made available, with international access ranked at 5.

2. Scientific excellence (20%): This ranked the community, with 5 indicating identifiable world leaders as users.

3. Extent of support for national priorities (10%): This was an assessment as to how well a given facility will meet the nation's stated research priorities.

4. Industrial impact (20%): This ranking was an assessment of the level at which the facility will serve the needs of the community and the degree to which it will generate wealth for the nation.

5. Instrument excellence (20%): A ranking of 5 indicated the instrument would be unique in the world and a ranking of 1 that it was not yet properly scoped.

Weightings were assigned to each of these five factors. New beamlines and other capabilities were evaluated against each factor; these values were adjusted according to the weighting and the totals ranked. The overall process is set out in Appendix 7.

It should be noted that the rankings do not reflect the importance of any one area of science compared with any other.

It is acknowledged that a consequence of the emphasis in this plan on future directions is that existing scientific and technology programs receive less attention. It must be emphasised that this decadal planning process aims to look forward over 10 years, in contrast to the NSC which focused very strongly on the demonstrated needs of the Australian synchrotron community.

6.2 Plan for growth

The core of this plan is the identification of the options and interests of the synchrotron community and an assessment of the importance and timing of potential outcomes. The proposed new beamlines and other capabilities are listed in an order that, in the opinion of the committee, it would be most appropriate that they be established. That being said, developments in technologies and demand can be expected to result in a re-ordering in later reviews of this plan. The committee believes that all of the listed capabilities will provide great benefit to Australia and New Zealand, and that all should ultimately be provided.

The community regards the top priority as completion of the initial suite of beamlines to world-class standard, along with access to international synchrotrons and Australian Synchrotron access facilitation. Current conditions suggest that the following new developments be subsequently introduced:

1. In the near term
- Circular dichroism
- Combined micro X-ray diffraction (XRD) and fluorescence (XRF)
- Medical imaging
- Extended-capability X-ray absorption spectroscopy

2. In the medium-term
- High-energy X-ray diffraction
- High-throughput micro computerised tomography
- Long, high coherence and nano-probe beamline
- Quick-scanning X-ray absorption spectroscopy (QXAS)
- Time-resolved reflectometry

3. Following scoping or further developments
- Micro lithography
- Nano lithography beamline
- Photoemission electron microscopy (PEEM)
- Resonant inelastic x-ray scattering (RIXS)
- Small molecule crystallography (SMX) beamline
- Tera hertz beamline
- Third protein crystallography beamline
- Vacuum ultraviolet
- X-ray microscopy (XRM) / scanning transmission X-ray microscopy (STXM).

This would take the total number of beamlines at the Australian Synchrotron to 23, consisting of the initial nine beamlines plus the 14 beamlines envisaged in this plan. The Australian Synchrotron would then be well towards its capacity of at least 30 beamlines.

This plan also includes additional capabilities on the initial beamlines. The community emphasises the importance of beamlines and other capabilities being world class.

The precise order in which these developments are introduced will be affected by factors such as availability of funding, demand trends and the technical ease with which the capability can be added. It is for such reasons that specific times for the implementation of these developments have not been suggested.

All facilities in the first grouping above have well established user communities in Australia and New Zealand. There are also significant user communities for the second grouping. The third grouping comprises technologies that would benefit from further scoping, to develop a broadly agreed concept; identify issues and barriers that need to be addressed in design and implementation; and propose options.

TOP PRIORITIES

Initial nine beamlines at world-class standard

The most pressing priority is that the initial suite of nine beamlines on the Australian Synchrotron (see Section 5.1) be completed to world-class standards. The facility would otherwise be disadvantaged in attracting users from other countries, demand for use of international facilities would be higher than desirable and, most importantly, the quality of Australian and New Zealand research conducted at the facility would be affected.

International linkage and access

No single synchrotron facility in the world meets all user needs—not if researchers are to deliver globally leading outcomes. The Australian Synchrotron will be no exception to this. For example, access to international facilities will be essential for users working in wavelength regions not available at the Australian Synchrotron, and for specialist experiments and techniques not available at the Australian Synchrotron.

In addition, the trend to increased international collaboration (see Section 4.3) will require continued support for researchers to travel to work alongside their collaborative partners.

As noted in Section 1, the synchrotron community recognises that the current planning process will not be 100% accurate in anticipating the techniques and resources that researchers will need in coming years. New techniques and technologies will inevitably emerge and it is imperative that our researchers have access to emergent resources and capabilities. Their choices will then provide feedback for the evolution of the Australian Synchrotron.

It is essential that resources are available for Australian researchers to continue to access overseas synchrotrons until Australian Synchrotron beamlines are available locally and thereafter for Australian science to have ongoing access to international synchrotrons to fill the inevitable gaps in capability of the Australian Synchrotron. The Australian Synchrotron will take time to fully develop and the funding and construction of beamlines will be an ongoing process for the foreseeable future, and certainly over the period of this plan.

Australian Synchrotron access facilitation

It is also vital in having a national facility that researchers have effective access to the Australian Synchrotron. The experience of the ASRP demonstrates that travel costs for access should be funded. This should address all research that meets merit-based access requirements. University-based researchers will not necessarily be funded for access through other grant programs.

There is a clear consensus that access will best be provided under a single framework that includes the allocation of access to the Australian Synchrotron as well as access internationally. This framework would direct a researcher to use the Australian Synchrotron where it meets the researcher’s needs, regardless of the facility that the researcher has used in the past. The community has high regard for the model used by the AMRFP. The application of this model would mean travel and subsistence funding would be provided after a peer-reviewed proposal has been approved either though a local peer-review process for the Australian Synchrotron or similar for an overseas synchrotron. The process must be able to respond rapidly to requests for travel support to international synchrotrons that have offered beamtime to Australian researchers.

NEAR TERM

Circular dichroism beamline

Circular dichroism is a recent development in synchrotron science and a CD beamline was proposed as part of the initial suite of beamlines (Beamline 12 in the NSC). Many CD users have not been synchrotron users, but CD on a synchrotron is more powerful than other forms of CD. CD is widely used for measuring the secondary structure (shape and chain folding) of complex molecules such as proteins. Thin films, bulk materials and the interfaces between thin films can be analysed. Researchers in life sciences, biology, drug design, plants and crops, physical sciences, advanced materials, functional polymers, micro-electronic and magnetic materials, biomaterials, agricultural technology and food technology all use this technique.

The CD beamline would be a UV-VUV bending magnet beamline producing circularly polarised light in the 5–15 eV energy range. Circular polarisation is achieved using optics rather than special insertion devices. The difference in the absorption of right and left circular polarised light is sensitive to molecular chirality, e.g. major sub-units of protein molecules. Solution samples are typically measured.

While the current user community is small and level of scientific outputs is low, this is an area of significant potential for Australia over the coming decade, with an opportunity for international leadership. Such a capability would complement the SAXS capabilities of the Australian Synchrotron.

Combined micro X-ray diffraction and fluorescence

The micro-XRD/XRF probe formed part of the initial beamline suite proposed in the NSC (Beamline 11) and the synchrotron community continues to regard this as a high priority. It was seen as the main microdiffraction capability. The technique offers the simultaneous determination of chemical composition (through XRF) and mineral type (via XRD) at a spatial resolution of ~1–3 microns. In addition, the diffraction capability allows measurement of grain orientation and distribution in 2D and 3D in a wide range of thin film and bulk materials. The proposed Beamline 11 is to be the only microanalysis instrument at the Australian Synchrotron with diffraction capability.

In addition, it is the only beamline primarily designed as a high-throughput industrial R&D tool. Such a facility would be an adjunct to laboratory-based microdiffraction and spectrometric techniques, such as electron-probe microanalysis, which are widely employed for materials characterisation. In particular, the availability of fast 3D phase and elemental mapping, with resolution down to ~1–2 microns, would provide information that is currently difficult to obtain from laboratory microdiffractometry and fluorescence spectrometry instruments. Micro-XRD/XRF has applications in physical sciences, advanced materials, mineral exploration and beneficiation, earth sciences, oil and gas production and distribution, chemical reactions and catalysis, forensics and advanced manufacturing.

In chemical analysis, the use of X-rays extends characterisation to lower limits of detection, while in mineralogical analysis a synchrotron-based instrument offers finer spatial resolution than laboratory-based instruments.

The facility would be a hard X-ray (4–40 keV) bending magnet beamline offering micro-fluorescence mapping combined with micro diffraction, and rapid switching between monochromatic, pink and white beam modes.

Extended-capability XAS

XAS probes the chemical and structural environments of elements in a wide range of forms including the liquid, solid and gaseous states. The Australian XAS community is well established and represents the largest fraction of the domestic user base, accounting for over half the experiments performed on the bending-magnet-based ANBF. Additional XAS beamlines are accessed at other international facilities when the photon flux, energy or focusing requirements cannot be satisfied at the ANBF. The breadth of the Australian XAS community is also readily apparent with users drawn from the medical, biological, biochemical, chemical, physical, materials, geological, environmental and engineering sciences. Accordingly, the first suite of beamlines for the Australian Synchrotron includes a wiggler-based XAS beamline that will satisfy many, though not all, of the requirements of the domestic user base. Projections of user demand predict this beamline will be the most oversubscribed of all the first-suite beamlines.

Construction or procurement of a second XAS beamline with extended capabilities is now recommended and is already part of planning for the Australian Synchrotron. Occupying a bending-magnet port, this beamline should span a photon energy range of ~1–12 keV. This ‘extended-capability XAS beamline’ would complement the wiggler-based XAS beamline and serve the crucial roles of providing the Australian XAS community with access to:

- The extremely important photon energy range of ~1–4 keV that will not be available on the wiggler-based beamline

- A stable bending-magnet source over the equally important energy range of ~4–12 keV to accommodate experiments not suited to a wiggler source and lessen the predicted extreme oversubscription on the wiggler-based beamline

- Micro-probe capabilities coupled with a scanable photon energy range not achievable on either the wiggler-based XAS beamline or the undulator-based microspectroscopy beamline.

The importance accorded to the photon energy range of 1–4 keV is governed by the inclusion of the K edges of aluminium, silicon, sulfur, chlorine, potassium and calcium. For example: aluminium has been linked to Alzheimer’s disease and thus has relevance to the medical and biological sectors, silicon forms the basis of the vast majority of electronic devices and thus is of significance for the physical, materials and engineering sectors, while sulfur is of considerable importance to the chemical, environmental and geological sectors given its role in catalytic reactions, acid sulfate soils and ore formation, respectively.

Transmission XAS measurements are typically best performed on a bending-magnet source to achieve data with the optimum signal-to-noise ratio. On a wiggler source, such measurements can be inferior as a result of instability in the optical components resulting from the excessive heat load generated by the wiggler. Furthermore and as above, a second XAS beamline is absolutely necessary to accommodate projected user demand from the largest fraction of the domestic user base.

The ability to focus the photon beam to sub-micron dimensions would significantly enhance and extend the capabilities of this XAS beamline and, accordingly, the user base would be considerably broadened given the numerous new applications.

For example, determination of the oxidation state of an element as a function of location within either a cell or inclusion is clearly of significance to, respectively, the biochemical and geological communities.

The technical complexity inherent with the extended-capability XAS beamline would be considerable. For example, over 1–4 keV absorption in air and window materials is high, while high quality monochromator crystals are difficult to obtain and diffraction grating efficiencies are very poor.

A focusing capability would add further complexity and should thus only be implemented if world-class performance is achievable. In such a case, consideration should also be accorded to an extended-capability XAS beamline without focusing, implementing the latter on a separate undulator-based beamline. Similarly, state-of-the-art detectors would be required to capitalise on the unique nature of the beamline.

Such challenges mean that few beamlines of this type have been well constructed worldwide. Given the extent of both domestic and international demand, this offers a very promising niche area for the Australian Synchrotron. High quality, user-friendly beamlines in this energy range are scarce and in high demand. The beamline would accommodate both conventional and focused beam (micro) X-ray absorption spectroscopy experiments. Such facilities are gaining strength due to growing scientific interest and demand at leading overseas synchrotron facilities.

Medical imaging station extension to imaging and therapy beamline

The possibility for establishing a state-of-the-art medical imaging facility is a unique opportunity for Australia and is extremely well matched to national scientific strengths. Work at other synchrotrons has demonstrated outstanding technical promise but has been hampered by inadequate infrastructure and systems for handling patients as opposed to just samples. With our excellent capabilities in medical research, advanced X-ray imaging techniques and fundamental X-ray physics (see Section 5), we can avoid the same problems.

Notably, the Australian Synchrotron is one of only two synchrotrons in the world that are in very close proximity to a major university and teaching hospital. The Australian Synchrotron is also distinguished by the ability to accommodate a suitable long beamline for a medical imaging extension and the state-of-the-art imaging clinic to be co-located with the synchrotron facilities will be a world first. The application of synchrotron techniques to medical imaging is being increasingly appreciated here and overseas. The challenge and opportunity for the next decade is to turn our strengths into real advances in synchrotron-based medical imaging. All the pieces are in place: fundamental science, medical research strength and interest, suitable ancillary facilities and the appropriate beamline.

The proposed extension is stage 2 of the Imaging and Medical Therapy beamline. The beamline would be extended through the facility wall to a station approximately 150m from the source. This would enable large scale imaging, including large animals and potentially humans, phase contrast techniques and ultra small angle scattering (USAXS).

MEDIUM TERM

High-throughput micro CT beamline

Micro CT is of interest to a remarkably large and growing community. There is some capability in the medical imaging beamline but if interest increases, greater capacity will be required. X-ray tomography provides 3D views of new man-made materials and disease-carrying organisms. It would enable examination of interior structure of objects at sub-micron voxel sizes and in sub-second time frames. It would also complement and extend the capabilities of laboratory-based approaches.

The proposed micro CT facility requires a bending magnet beamline. A micro CT facility is already planned on the Australian Synchrotron's Imaging and Medical Therapy beamline, but as one of a number of supported techniques it is unlikely that this beamline will meet anticipated demand. A dedicated beamline would be designed for high speed and throughput. 2BM at the APS would be a good model as it can acquire and reconstruct tomographic images in a few minutes per sample. The automated high-throughput capability would be linked to appropriate massive-data set handling and high performance super-computing capabilities as well as resources in information extraction.

Long, high coherence and nano-probe beamline

Australia has a small but very high quality community in the areas of X-ray coherence and X-ray coherent imaging. A high coherence beamline requires an undulator source combined with as long a beamline as can be accommodated, and the Australian Synchrotron site offers the possibility of building quite long beamlines. If such a beamline were to be built it would represent a capability that would be world-class and potentially unique. This convergence of community and opportunity suggests that the construction of such a facility would support very high quality science and would attract substantial international users. Applications would include coherence-based techniques such as non-crystalline imaging, but this beamline would deliver the highest brightness X-rays possible at the Australian Synchrotron, and so would be useful for any brightness-limited technique.

Such a beamline would be further enhanced by combining it with a very high resolution scanning microscopy/nanoprobe facility. Such a facility would allow the scanning of samples with a resolution of possibly 20 nm, enabling the community to fully utilise the coherence of the source, produce a very exciting facility and serving the needs of two scientific communities.

Quick-scanning X-ray absorption spectroscopy

Quick-scanning X-ray absorption spectroscopy would be available through an addition to the wiggler-based XAS beamline, one of the first beamlines scheduled to become operational at the Australian Synchrotron. This would be achieved by installing a second, specially designed monochromator that can rapidly and repeatedly scan a selected XAS energy range. The monochromator is commercially available and space has been left on the XAS beamline for this upgrade. QXAS would push the XAS beamline to the limit and create a unique international capability. QXAS data could be measured in 50 milliseconds rather than approximately one hour for a normal XAS spectrum. Time-varying processes such as catalytic chemical reactions could thus be studied over this time scale and detailed kinetics with both scientific and technological significance could be determined. Additional high-performance detectors capable of acquiring and processing QXAS data would also be required and should be procured concurrently with the second monochromator.

Time-resolved reflectometry

Reflectometry is used to study the structures of thin films on solid and liquid substrates. Australia has several active groups using this technique at synchrotrons and neutron facilities, and one of the initial beamlines at the OPAL reactor is a neutron reflectometer. Barring extensive growth, the needs of Australians for ‘traditional’ angular dispersive reflectometry can be catered for at overseas synchrotrons (such as ChemMatCARS at the APS) for the next decade. However, the community has the capability for building an energy dispersive instrument that would be a world first. This instrument could be built on a bending magnet beamline, and involves directing a white or pink beam onto a surface and achieving Q resolution by either using an energy dispersive detector or energy analysing the reflected beam using optics. Such a beamline would have unique capabilities to study time-dependent processes that cannot be examined at any other facility, and would attract users from around the world.

High energy X-ray diffraction

A high energy (> 50 keV) X-ray diffraction beamline at the Australian Synchrotron was addressed as part of the NSC; the original intention was to transfer the powder diffraction beamline from a bending magnet to a wiggler source. However, due to the growing demand for access to a high energy diffraction facility, it is now proposed to add a new beamline specifically designed for high energy methods. This would complement the low energy beamline that is being installed as part of the initial suite of nine beamlines. High energy X-rays offer some exciting extensions to X-ray diffraction capabilities.

For example, tomographic energy-dispersive diffraction imaging is a relatively new technique that combines diffraction computerised tomography with a white beam and multiple detectors/collimators to allow fast imaging of structure, e.g. crystalline phase distribution in a material. This measurement requires well-collimated energy-dispersive detection to gain mineralogical information from small (~10 micron) volume elements within a bulk sample or reaction vessel, experimental cell or prototype industrial process. Since the diffraction pattern is measured using an energy dispersive detector, the d-spacing resolution is generally poorer than conventional angular dispersive techniques. The use of TEDDI has been demonstrated at the Daresbury synchrotron facility in the UK, and improvements could be made through increased detector energy resolution.

TEDDI has broad ranging applications to in-situ measurement of processes that would be of great benefit to industry across a range of fields, including mineral processing. The strength of this hard X-ray technique is in its ability to follow mineralogical changes inside reaction vessels that emulate the extremes of temperature, pressure, pH and composition found in real mineral processing plants. There are a wide range of other applications, including crystallisation mechanisms and kinetics in pharmaceutical production, studies in aquifer models—which require an understanding of connected and closed porosity—and applications in smelting, chemical engineering, energy technology, casting and manufacturing.

Whilst conventional powder diffraction allows determination of the average structure of a material, methods that take into account the total scattering of the material, such as diffuse scattering or pair-distribution-function (PDF) analysis, allow determination of short-range order. The latter method benefits from high energy X-ray (or neutron) sources, low background and data collection out to high Q-space, thus it requires a synchrotron source capable of energies in excess of 50 keV. PDF analysis is particularly useful for determination of the atomic structure of nanocrystalline and poorly ordered materials, and is a vital technique to materials development. In addition, residual stress analyses greatly benefit from high energy X-rays as they allow thicker samples to be effectively analysed.

REQUIRING FURTHER SCOPING

Micro lithography

A micro lithography beamline would be an expansion on the facility proposed in the NSC (Beamline 13). The science case proposed a beamline for “deep X-ray lithography” aimed at the manufacture of high aspect ratio micro devices. This includes hard X-ray processes (~10 keV and above) such as LIGA where a die is made using the beamline and parts manufactured elsewhere, and direct micro machining.

Nano lithography beamline

Nanolithography is an emerging area of interest as a enabling tool, and developments in this area should be monitored. It appears to be a capability that would be internationally attractive. All beamlines employing a micro probe could benefit greatly from such a lithography facility, not only as an in-house source of cutting-edge X-ray diffractive optics, but also of test patterns, reference samples etc. It has great potential for applications from engineering to medicine, such as nanophotonics, bio-sensors, guided self-assembly, new diffractive optics, surface templating, tissue scaffolds and microfluidics.

Over the coming decade researchers are expected increasingly to need patterning from the submicron to the few-tens-of-nanometer level. In this respect, X-ray nanolithography is very cost-effective compared with systems such as e-beam or extreme UV lithography. X-ray nanolithography is the only technology available today that can reach the sub-70nm range while meeting every node along the way. It is fast, robust, reliable, can do high resolution and high aspect ratio at the same time, and can print large areas.

Resonant inelastic x-ray scattering
RIXS is a soft or hard X-ray technique whereby dipole forbidden transitions such as d-d excitations are measured in resonance with allowed excitations. Soft X-ray RIXS, studying the 3D transition metals using their L edges up to 1 keV, is an active field as important materials properties can be measured, such as magnetic properties and metal insulator transitions in high Tc materials. A high-resolution soft X-ray beamline coupled to a high resolution X-ray emission spectrometer is required (this is a photon in – photon out technique). RIXS could be implemented initially as an add-on to the soft X-ray beamline.

Photoemission electron microscopy
In PEEM, the electron emission from a sample is imaged using adapted electron microscope optics, i.e. spatial resolution is derived from the detector, not the X-ray beam. Spatial resolution with the latest generation PEEM is around 20 nm. PEEM could be implemented on a branch line or an additional endstation on the soft X-ray beamline at the Australian Synchrotron.

Small molecule crystallography beamline
A dedicated SMX beamline has also been proposed as a response to an anticipated sharp rise in demand for beamtime from that community. This would introduce new capabilities and address a number of trends identified in Section 3. SMX characterisation applications include green chemistry, bio-mimetic materials, minerals, catalysis, drug design, nanotechnology, hydrogen storage devices, 'smart' materials, micro-magnets, molecular switches and sensors, superconductors, optical devices and information storage devices and systems. The SMX beamline would use the properties of synchrotron radiation to probe magnetic structures, fine details of catalysts and absolute configuration.

A dedicated SMX beamline would allow the introduction of environmental cells to enable the probing of samples under non-standard or extreme conditions, such as extremely low temperatures and high pressures. Time-resolved laser-pump/X-ray-probe small molecule single-crystal diffraction techniques would allow transient photo-induced electron density perturbations (with millisecond to picosecond lifetimes) to be captured, resolved and quantified. The development of other 'pump' mechanisms, such as electrically and mechanically induced pulses would be important for industry, in such areas as electroluminescence, triboluminescence and piezoelectricity.

THz beamline
Applications of THz radiation (1 to several THz) are emerging very quickly and this is becoming a very 'hot' area of science. Most potential applications so far are in imaging, including medical imaging and security related imaging such as weapons and explosives searches. Australia has a small, high quality community in this area and there are few beamlines dedicated to this research area in the world. Such a beamline would be an important facility on the world stage.

A THz beamline would use a bending magnet source; the electron bunch length and the radiation wavelength are comparable leading to potential coherent emission producing large intensity gains.

Third protein crystallography beamline
The initial PX beamlines on the Australian Synchrotron will probably have demand above capacity. The extent of demand for a third PX beamline should be monitored. Such a facility might be primarily for in-crystal screening of drugs, which is highly time-demanding, or to address the emerging trends in structural genomics (see Section 3.1). This could be underpinned by a commercial analytical service. A key indicator will be industry's willingness to fund such an additional capability.

Vacuum ultraviolet
A VUV spectroscopy beamline was part of the initial suite proposed in the NSC (Beamline 7). The beamline would operate over an energy range from 10-20 eV (as low as possible) to around 350 eV using a high K undulator source. VUV enables a wide range of applications, such as angle-resolved photoemission spectroscopy, solid state studies, gas phase studies, adsorbate studies and biosystems research. Although this is an important technique, the current user community in Australia is small and there are question marks around the suitability of this technique for a 3 GeV synchrotron such as the Australian Synchrotron. Developments in Canada should be monitored while Australian and New Zealand researchers continue to access VUV facilities in other countries.

X-ray microscopy scanning / transmission X-ray microscopy
There is a range of soft X-ray microscopies, both full field and scanning. All require a high brightness, high resolution, soft X-ray beamline – that is, an undulator source. This would fit well with the Australian Synchrotron as the peak undulator performance from a 3 GeV ring is in the soft X-ray (~1 keV) range. Techniques include STXM; scanning photoemission electron microscopy where the beam is focused with a zone plate, the sample scanned, and the transmitted beam or photoelectrons are measured respectively; and full field X-ray microscopies, again usually using zone plate optics. The energy range is roughly 100 eV to 2 keV, and the spatial resolution at energies under 1 keV is pushing below 20 nm.

This facility has strong demand within Australia and comparable facilities exist in many other synchrotrons. However, the demand is from users outside of the established synchrotron community and so it does not have a champion able and prepared to lead the project. For this reason, though desirable, the establishment of such a facility will require an explicit strategic decision, supported by investment.

6.3 Capability development

Capabilities in accelerator science, X-ray optics and detectors must be developed strategically and in parallel with the establishment of facilities at the Australian Synchrotron.

Ancillary facilities
All world-class synchrotron facilities have on-site accommodation. The synchrotron user community regards suitable convenient accommodation for visitors as a critical feature of access and community-building.

Undertaking experiments using animals requires the establishment of a small animal facility. Arrangements will need to be made for housing and ethics oversight, and care taken that small animal imaging does not cause other problems.

Laboratory facilities, such as clinical laboratories, are also going to be required either at, or in the vicinity of the Australian Synchrotron. However, the decadal planning committee believes that for the time-being other arrangements should be made for studies and analysis involving human patients. There is also potential for laboratories using other techniques to be colocated with the Australian Synchrotron.

Accelerator science

Synchrotron-based science is, in many ways, a practical spin-off from the experimental nuclear and particle physics community. Both areas require developments in accelerators and in detectors. Similarly, much of medical therapeutics also depends on accelerator and detector physics for the creation of radiopharmaceuticals. In Australia these areas remain separated, joined only by the fact that hospitals keenly employ individuals with PhDs in particle and nuclear physics for their medical physics programs. The committee believes that synergies in these areas would be very productively harnessed by the establishment of a program in accelerator science in an Australian university. Australia does not currently have any programs in accelerator science and such a program could also be associated, or integrated, with a program in detector technology (see below).

New sources are continuously emerging and some of these may have an influence over the next 10 years (see Section 4.1). Although they will not supplant the role of a synchrotron, the community must be aware of the latest developments and ensure that resources are always used optimally, shifting experiments to cheaper sources if and when it is appropriate.

X-ray optics

Precision innovative optics will be critical to future beamline development at the Australian Synchrotron. To this end, the local synchrotron community should support and develop local advanced capabilities in this field. The most significant optics development for Australian and New Zealand researchers is expected to be nano- and micro-focus. Capability should be developed in diffractive optics, crystal optics and mirror optics.

The vast majority of leading synchrotron facilities around the world have associated or in-house X-ray optics development facilities. We recommend that the Australian Synchrotron also establish such a capability as a priority. This would build on expertise currently within CSIRO (CSIRO Precision Optics, Sydney).

It is critical that the Australian Synchrotron harnesses and promotes Australia's existing limited and dispersed capabilities in this area. Collaboration with the neutron community is expected to be fruitful as many of the technologies have substantial commonality.

Detectors

The throughput, efficiency and detection limits or spatial or momentum resolution of many Australian Synchrotron beamlines – and ultimately success of applications – will be determined by the detector systems used.

Detectors themselves, or the properties of conventional approaches to data acquisition, will limit performance in many cases. The long-term competitiveness of the Australian Synchrotron will be determined, to a large part, by attaining and maintaining detectors that are state-of-the-art.

Australia has a small detector development community which is concerned with both synchrotron-science and particle physics. This capability should be nurtured. The Centre for Synchrotron Science at Monash University, CSIRO, the School of Physics at the University of Melbourne and the Centre for Medical Radiation Physics at the University of Wollongong have active programs in detector development, for synchrotron and medical applications and high-energy physics, and have scientists and engineers with world-class expertise and active collaboration with overseas developers. Australia should ensure that these programs receive strategic support and encouragement to continue to develop their collaborative efforts.

Methods

The synchrotron community also anticipates benefits deriving from fit-outs at the Australian Synchrotron for Physical Containment Levels 2 and 3 (PC2 and PC3), especially in health-related research and radiological facilities. PC2 facilities are required for knockout animals and tissue and there will be a significant demand for such tissue to be investigated using a variety of synchrotron techniques. This demand is supported by increasing concern about biosecurity.

Submissions to the review identified imaging as a key capability that offers substantial benefits to the Australian community. In particular, there is perceived to be a need in the areas of phase-contrast imaging and in soft X-ray microscopy. Australia is a world leader in phase-contrast imaging and the application of hard X-ray microscopy to biological and medical applications and we are in an ideal position to build on this expertise for soft X-ray microscopy, although the nation does not have international-class expertise in the latter area. This would appear to be an area in which strategic investment should be made.

High-resolution soft X-ray microscopy has emerged from the community consultation as an area in which there is significant pent-up demand. Australia does not yet have leading expertise in the development of the technique, which is quite mature at other synchrotrons, and the committee recommends that the nation develop expertise and facilities as a strategic priority.

6.4 Skills development

Ongoing training must be provided for academic and industrial users to build the expertise required to make optimal use of the facilities at the Australian Synchrotron and overseas.

The community recognises an important need for increased training of more beamline scientists and technicians. It sees value in postdoctoral fellowships being established at the Australian Synchrotron, joint appointments between universities and the Australian Synchrotron, support for postgraduate researchers and forums for early career researchers such as summer schools.

The capabilities proposed in this decadal plan also require complementary development of skills for them to be fully utilised and the outcomes taken up. The ASRP Fellowship scheme has been a major success, with many of its ‘graduates’ taking up positions at the Australian Synchrotron. Scientists of this calibre must continue to be attracted, trained and retained, especially to give them expertise in the right range of disciplines. This is only possible if continued attention is paid to the development of interdisciplinary science.

It is also vital that the Australian and New Zealand synchrotron communities maintain the absorptive capacity that will be needed to identify, design, select and fully utilise enhancements to the Australian Synchrotron in the future. The continuation of overseas access will provide a mechanism to enable skills to be developed at other synchrotrons before it is decided whether to introduce similar capabilities at the Australian Synchrotron.

6.5 Government and community engagement

The synchrotron community recognises that it must actively engage with governments, the broader scientific community and the wider public if our nations are to take full advantage of the trends that are emerging. This includes national as well as the Australian State Governments, and governmental bodies that transcend State and national boundaries. The momentum that has been built up must not be lost. In turn, the synchrotron must continue to monitor developments in government policies in science, industry and medicine, and adapt its planning accordingly.

The broader research community is not necessarily cognisant of the opportunities to use synchrotron technologies to address emerging areas of science or how to use some of the new synchrotron techniques, and actions must be put in place to address this.

6.6 Industry engagement

The ASRP and Australian Synchrotron Project have been engaging with industry to demonstrate how synchrotron science can deliver value, even before synchrotron techniques become locally available.

Industry users of the Australian Synchrotron are expected to access the facility both through collaborative programs with established research and development providers (such as universities, CSIRO and CRCs) as well as directly with the facility. Collaboration is expected to be the main access route, particularly in the early stages of the Australian Synchrotron's development.

There have been and will be numerous problem-solving applications that translate to incremental improvements in businesses. Breakthrough opportunities must also be sought and encouraged, both from accepted areas (for example, protein crystallography leading to rational drug design) and new areas at the interfaces of the traditional science and technology disciplines. The unique feature of the Australian Synchrotron will be that leading scientists and technologists will be working together in the same place. A well-delivered industry program will take advantage of this, making the Australian Synchrotron a national focal point for innovation that leads to industry benefits.

The current industry engagement program focuses on awareness-raising in the potential user community. Networks are being established – through existing networks where possible – and an education program is in place. An industry synchrotron access program is providing funds for short demonstration projects for the private sector. Approximately 60 projects have been identified, of which 35 have been or are being taken forward. It is recommended that a similar demonstration project program be implemented at the operational facility.

A number of industry-focused projects within the overall project are being developed for the next stage of industry engagement. These include:

- Ramp-up of industry synchrotron access programs

- Development of a general purpose synchrotron micro-probe with applications in the minerals and manufacturing sectors

- Development of lithography facilities to complement other microfabrication techniques

- Set-up of a protein crystallography consortium

- Set-up of an instrument and detector group

These projects are intended to include participants from the private sector and publicly funded research organisations. The instrument and detector consortium has, in part, been integrated with the CRC for Biomedical Imaging Development. Further opportunities for spinning out synchrotron-related technologies should be pursued.

A marketing plan for the facility has been developed, based on providing a user-friendly service to industry-related users. The service will need to include synchrotron analysis, rapid and timely access, appropriate intellectual property (IP) protocols, quality assurance, integrated safety practices, technical consulting and technical support. The plan provides a framework for taking forward industry engagement in the first few years of operations.

Programs and systems for economic value capture of synchrotron-related activities will probably include the provision of some limited funding for developing suitably detailed business cases that provide companies with a compelling reason for investment in technologies developed by the synchrotron users. Such a scheme provides a pathway to industry for synchrotron-related technologies, rather than bringing industry applications in to the facility.

Industry engagement in other countries

It will be critically important for the community to explore how the facility can best interact with industry by studying international best practice. For example, several overseas synchrotrons provide problem-solving services to industry. Overseas experience is that proprietary access typically runs at around 5% of total beamtime, with 10% a maximum allocation. However, the total beamtime percentages that include industry collaborations are considerably higher. For example, the ESRF allocates approximately 30% of beamtime for industry-related projects, including both merit-based and proprietary access.

By emphasising the need for industry participation from its foundation, the Australian Synchrotron has an opportunity to increase the levels of industry engagement and proprietary access by:

- Encouraging industry collaboration through merit-based access

- Making proprietary access available to public sector researchers who want rapid access and full service provision

- Developing a range of services, including systems for quality assurance

- Identifying routine synchrotron analyses beyond protein crystallography.

National Industry Advisory Committee

NIAC provides industry input on the technical specifications of beamlines and the strategic implications of the structure of the operating entity. The committee includes members from all States and across industry sectors. The continuation of such a committee, or at least representation from the private sector in key advisory roles, will enable significant industry input into development of the facility.

7. resourcing

This strategic plan is based on prioritising the investments that should be made over a decade.

It must be re-emphasised that a minimal funding model is not viable. It will not yield the results that are sought by any of the stakeholders from the Australian Synchrotron and our ability to access facilities in other countries. Ongoing funding requires a commitment to new instrumentation and refurbishments. Most synchrotrons build 10% capital into their annual operating funds. Moreover, unless operating funding covers costs associated with providing users with access, facilities will be under-utilised and the user base will not grow. The addition of new capabilities to meet emerging areas of science especially requires financial support for user access, especially for new users.

As noted in Section 5.1, the Australian Synchrotron has attracted substantial investments in the initial suite of beamlines from universities, public-sector research organisations and governments. These organisations have become Foundation Investors in the Australian Synchrotron Company.

Funding for the first two of the top priorities listed above – namely completion of the initial nine beamlines to world-class standard and international access – is to come from the Australian Government's National Collaborative Research Infrastructure Strategy (NCRIS).

The community will also look to other sources for infrastructure funding, for example, the ARC's Linkage Infrastructure, Equipment and Facilities (LIEF) program. A CD beamline, for example, is within the range funded by the LIEF program.

The New Zealand Government's Research Infrastructure Advisory Group (RIAG) will also be examining high-cost research infrastructure of strategic importance for New Zealand. RIAG will provide expert advice to the Ministry of Research, Science and Technology on the scientific case and strategic relevance of infrastructure proposals.

It must be emphasised that all world-class synchrotron facilities have stable, long-term operating funding. The synchrotron community places strong emphasis on ongoing operating funding being confirmed prior to the facility opening in 2007. Overseas experience demonstrates the damaging effects of a shortage of operating funds and year-to-year funding uncertainty.

8. transition over the next few years

The opening of the Australian Synchrotron and its ongoing evolution will bring enormous advantages for Australian and New Zealand researchers, as have been discussed extensively in the NSC and the New Zealand Science Case. However, the change also presents the synchrotron community with large transitional challenges. There will be new access arrangements, changes to review arrangements, new operations staff with whom to work, and a major shift in the way that the members of the community see their roles.

The Australian synchrotron community regards it as imperative that ongoing funding is provided for access to international facilities when ASRP funding under the MNRF program ceases.

Users who have maintained international relations through visits to synchrotrons overseas should consider new ways to foster these relationships once they are generally using the Australian Synchrotron. Options include inviting major collaborators to visit Australia and increasing use of eResearch for collaboration.

8.1 New advisory arrangements

When the new access and governance arrangements commence, users will be directly involved in the Australian Synchrotron at a new level, for example participating in peer review of proposals. Users will have a role with the Australian Synchrotron akin to the role that they have played in the ASRP since it was established.

As discussed above, a single framework for access to the Australian Synchrotron and overseas synchrotrons would provide the most efficient process for researchers and the best use of research access funds. It would also maximise the value of advisory teams. On this basis, review arrangements for the Australian Synchrotron should include access to overseas facilities where appropriate. This approach has wide support.

8.2 Collaboration with complementary facilities

Increased collaboration with other characterisation facilities has also been proposed. Apart from the integrated use of complementary characterisation techniques, this could involve sharing information on best practice, discussing current and emerging technologies, managing systems infrastructure requirements, advocating access and support issues such as funding and promotion, and encouraging cross-fertilisation of ideas.

In line with the world-class nature of the Australian Synchrotron and facilities such as OPAL, it is vital that cooperative activities are also of a high quality.

8.3 Major milestones

2006

- Selection of the operator for the Australian Synchrotron. Commencement of the transition period for the operator.

- NCRIS Investment Plan prepared.

- Launch of the ASRP end-station at the NSRRC, which was in effect the first Australian Synchrotron instrument to be commissioned.

- AMRFP contract renewed.

2007

- Opening of the Australian Synchrotron.

- MNRF funding for the ASRP expires at the end of June 2007. Transitional funding through NCRIS to enable Australians to continue to access overseas synchrotrons until Australian Synchrotron beamlines are fully operational.

- Detailed planning commences for high priority beamlines, based on available funding.

- Hand-over of Australian Synchrotron operations responsibilities to operator.

- First five beamlines achieve photons on sample and commence user operations.

- First formal review of this strategic plan.

2008

- Initial suite of beamlines operational.

- Commencement of transition from access via the ASRP to the Australian Synchrotron.

- Engagement with government and the synchrotron community regarding the future of international synchrotron travel funding under the AMRFP and the potential for closer integration of international and national synchrotron access arrangements.

2009 and 2010

- AMRFP three-year contract subject to renewal in 2009.

- 2010–11 financial year marks last year of the current NCRIS funding program.

2017

Synchrotron science in Australia and New Zealand: 2017

In 2017, the Australian Synchrotron will continue to be a state-of-the-art facility supported by programs in accelerator science, detector development and X-ray optics. It will be regarded as a jewel in Australian and New Zealand science, for its contributions to research and the economy, including new industries that were not even conceived a decade earlier.

Australian and New Zealand synchrotron users will have contributed to important improvements in healthcare for their fellow citizens and supported exports of healthcare products around the world. Their research will have ensured ongoing competitiveness in our agricultural, minerals and manufacturing industries. Damage to the landscape will have been held back or remediated through innovations not foreseen in 2007.

The user community will number between 1500 and 2000, with 500–800 principal investigators. The community size will continue to grow, due to ongoing satisfaction with the facilities and new users taking up synchrotron-based science. Industry will be deeply involved. The vast majority of users will be people who in 2007 would never have considered using such a facility.

Researchers in both Australia and New Zealand will be recognised as being at the forefront in using synchrotrons. They will be regarded as desirable partners for international collaborations, which will be very much the norm for research teams. Users from around the region will be attracted to use the facility.

Because the Australian Synchrotron will be a world-leader in synchrotron-based medical imaging, scientists will be coming from all over the world to use it. We anticipate that it will be one of the top three facilities in the world in coherent X-ray science. Melbourne in general will be seen as a world-leading region in X-ray imaging. The facility will be a major regional facility for structural biologists and materials scientists, and will be seen as a central piece of infrastructure by the structural biology community.

The Australian Synchrotron will be immersed in a science park and will host a range of capabilities in addition to those based on the synchrotron itself.

The facility in 2017 will look substantially different to the way it did when it was opened. New beamlines, detectors and optics will have been added. About 23 beamlines will be operating, taking the synchrotron to more than two-thirds of its full capacity. Beamlines and the accelerator will have been refurbished to maintain their competitiveness.

Many researchers will only rarely see the building, however, because they will access beamlines and laboratories remotely. Enormous databases will also make the research data of others easily available.

The Australian Synchrotron will be servicing the vast majority of Australian and New Zealand demand. However, Australian and New Zealand scientists will also still use top facilities around the world, especially the new fourth generation facilities, ensuring our scientific outputs continue to be world-class.

But the days of getting on a long flight to conduct all research on synchrotrons will be the subject of nostalgia.

recommendations

Developments across synchrotron-based science should be monitored and this plan amended accordingly in coming years. (Sections 1.2, 6.2, 8.3). In addition to our detailed recommendations, we regard investment in eResearch modes as essential in the near future for scientific experimentation and communication (Section 4.5).

1. The initial suite of beamlines should be completed to world-class standards. (Section 6.2)
2. Resources should be made available for Australian researchers to continue to access overseas synchrotrons until beamlines are available locally, and for capabilities not available at the Australian Synchrotron, including access to fourth generation sources. Resources should also be provided for travel and subsistence costs associated with users accessing the Australian Synchrotron. (Section 6.2)
3. Access will best be provided under a single framework that includes the allocation of access to the Australian Synchrotron as well as access internationally. (Section 6.2)
4. The Australian Synchrotron should be continually upgraded and evolve in its capabilities.

- In the near term this would be with the addition of circular dichroism, combined micro X-ray diffraction and fluorescence, medical imaging and extended-capability X-ray absorption spectroscopy.

- High energy X-ray diffraction, high-throughput micro computed tomography, a long, high coherence beamline, quick-scanning X-ray absorption spectroscopy and time-resolved reflectometry would be subsequently introduced.

- Areas that require scoping or are emerging are micro lithography, nano lithography, photoemission electron microscopy, resonant inelastic X-ray scattering, small molecule crystallography, a THz beamline, a protein crystallography beamline that would be the third at the Australian Synchrotron, a vacuum ultraviolet beamline and X-ray microscopy / scanning transmission X-ray microscopy. (Section 6.2)

5. Suitable convenient accommodation should be provided for scientists visiting the Australian Synchrotron. (Section 6.3)

6. Developments in accelerators, detectors, robotics for remote access and X-ray optics should also be introduced in collaboration with research partners. (Section 6.3) Ongoing funding for the Australian Synchrotron should include a commitment to new instrumentation and refurbishments. (Section 7)

7. Australia's X-ray optics and detector development communities should be nurtured. (Section 6.3)

8. The capabilities proposed in this strategic plan should be accompanied by complementary development of skills among users, training of additional beamline scientists and technicians and development of the absorptive capacity required for future enhancement of the Australian Synchrotron. (Section 6.4)

9. The synchrotron community should actively engage with governments, the broader scientific community and the wider public. (6.5)

10. Industry-related programs should include a demonstration project program, further development of capabilities attractive to industry, rapid and timely access, appropriate IP protocols, quality assurance, integrated safety practices and technical consulting and support. A successor to the National Industry Advisory Committee should be established. (Section 6.6)

Appendices

appendix 1

Introduction to synchrotron-based science

A synchrotron accelerates electrons to extremely high energies and almost to the speed of light. As the electrons are deflected through magnetic fields they create extremely bright light. The light is channelled down beamlines to experimental workstations where matter can be 'seen' at the atomic scale.

Synchrotrons play a pivotal role in research. Synchrotron radiation provides capabilities that are, in many cases, unique and that surpass conventional laboratory sources in intensity, brightness and photon energies by many orders of magnitude. The power of synchrotrons is increasing at a phenomenal rate, exceeding even the rate of development of computer technology.

Synchrotrons are often associated with X-rays, but a synchrotron is not just an X-ray facility. It is an extraordinarily multi-disciplinary R&D facility that produces intense light across almost the whole of the electromagnetic radiation spectrum. Using the extremely intense infrared, ultraviolet, soft and hard X-ray, and visible light beams produced at synchrotron facilities, scientists can determine the structure of materials over a huge range of length scales, from macroscopic to atomic levels; study the chemistry of surfaces and interfaces; analyse tiny trace element concentrations in micron-sized samples; measure disordered systems such as minerals processing solutions and catalysts; obtain three-dimensional computed axial tomography scan images with micron resolution, and so on. The materials that can be examined range from crystallised proteins and living cells, to hair fibres and mineral deposits, and even to humans and whole animals.

Synchrotron-based research is fast-moving. Research using synchrotron radiation drives progress across the most innovative fields of industry today, including biology and biotechnology, chemistry, physics, electrical and electronic engineering, environmental engineering, mineral exploration and processing, life sciences, materials science and medicine. Synchrotron light has also become an essential tool for investigations in archaeology, palaeontology, geology and many other scientific disciplines.

appendix 2

Membership of the Expert Subcommittee on Decadal Planning

Keith Nugent, School of Physics, The University of Melbourne and Deputy Chair, National Science Advisory Board, Australian Synchrotron Project: To chair the committee and to provide advice on the directions of X-ray imaging and applications requiring very high brightness sources.

Rob Lamb, School of Chemistry, University of NSW and Chair, Policy and Review Board, ASRP: To act as Deputy Chair and to provide advice on directions on the use of synchrotron methods in surface chemistry.

Richard Garrett, Director, ASRP: To provide an overview of the development of synchrotron instrumentation, and to provide advice on directions in the development of the Australian and New Zealand communities.

Ian Gentle, Department of Chemistry, University of Queensland: To provide advice on emerging directions in small angle scattering and grazing incidence methods.

Mitchell Guss, School of Molecular and Microbial Biosciences, University of Sydney: To provide advice on emerging directions in structural biology.

Peter Hammond, School of Physics, University of Western Australia: To provide advice on emerging directions in the use of synchrotrons to atomic physics, and applications with soft X-rays.

Rob Lewis, Centre for Synchrotron Science, Monash University: To provide advice on emerging directions in the applications of synchrotrons to medicine and medical imaging.

Jim Metson, Department of Chemistry, University of Auckland: To provide advice on emerging directions in surface characterisation methods, and to represent the New Zealand community.

Mark Ridgway, Research School of Physical Sciences and Engineering, Australian National University: To provide advice on directions in the development and application of X-ray absorption and related techniques to materials.

Gerry Roe, Industry Advisor, Australian Synchrotron Project: To provide advice on emerging industrial applications, and to represent the Australian Synchrotron Project.

Chris Ryan, CSIRO: To provide advice on emerging directions in X-ray microbeam science and in the application of synchrotrons to minerals.

appendix 3

Submissions

James Alexander McLure	Flinders University
Jeff Corbett	Stanford Synchrotron Radiation Laboratory
Herman Winick	Stanford Synchrotron Radiation Laboratory, Stanford Linear Accelerator Center and Stanford University
Matthew Hall	Johns Hopkins University / National Institute of Health Bethesda
Bill Skinner	Ian Wark Research Institute, University of South Australia
Michael Swain	Faculty of Dentistry, University of Sydney
Jose N. Varghese	CSIRO Molecular and Health Technologies
Graeme Gainsford	Industrial Research Limited, New Zealand
Graeme Edward	Department of Materials Engineering, Monash University
Bruce Xu	University of Queensland
David Parsons	Women’s and Children’s Hospital, Adelaide
Rosanne Guijt	University of Tasmania
Martin Barlass	Department of Primary Industry, Victoria
Robert Leckey	La Trobe University
Anton Stampfl	Australian Nuclear Science and Technology Organisation
Carolyn Dillon	University of Wollongong
Michael Parker	St Vincent’s Institute
Sudarshan Ramachandran	Victorian Partnership for Advanced Computing
Andrea Gerson	University of South Australia
Peter Kemeny	Kemeny Consulting
John McDougal	Monash University
Mibel Aguilar	Monash University
Derek Abbott	Centre for Biomedical Engineering, University of Adelaide
Alan Buckley	University of New South Wales
Carl Chen	Swinburne University of Technology
Barbara Etschmann	CSIRO Exploration and Mining
Bayden Wood	Monash University
Hugh Harris	University of Sydney

Enzo Lombi, Jose Varghese, Chris Ryan, Weihua Liu, Ian Madsen, Rob Hough, Steve Wilkins, David Hay, Jeff Church, Stephen Hawkins, Keith Millington, Sarah Harmer, David French, Colin MacRae, Matteo Altissimo and Roger Netterfield	CSIRO
Mitchell Guss	School of Molecular and Microbial Biosciences, University of Sydney
Jim Metson	Department of Chemistry, University of Auckland
Ian Madsen and Steve Wilkins	CSIRO
Efim Gluskin	Advanced Photon Source
Bruce Cowie	Australian Synchrotron Project
Pete Hammond	School of Physics, University of Western Australia
	National Industry Advisory Committee, Australian Synchrotron
Rob Lewis	Monash Centre for Synchrotron Science
Jamie Rossjohn	Department of Biochemistry & Molecular Biology, Monash University
Gerard Roe, Erol Harvey, Andrew Peele, Matteo Altissimo and Peter Kemeny	Synchrotron Lithography Science Case Working Group
Andrea Gerson, with Joe Cavallaro Kym Dowling Sarah Harmer Maria Hrmova Gene Ice Ian Madsen Stewart McIntyre Ruben Reninger Gerry Roe Neville Smith Bill Tomlinson	University of South Australia CSIRO University of Ballarat CSIRO University of Adelaide Oak Ridge National Laboratory, USA CSIRO University of Western Ontario, Canada Scientific Answers and Solutions, USA Australian Synchrotron Project Advanced Light Source, USA Canadian Light Source, Canada
Mark Ridgway on behalf of the XAS Beamline Advisory Panel	Australian National University, University of Sydney, ASRP, Australian Synchrotron Project
Chris Glover	Australian Synchrotron Project

appendix 4

Consultation paper responses

1. Australian X-ray Analytical Association
2. Western Australian Synchrotron Users Group
3. Mitchell Guss
4. Anton Stampfl, Australian Nuclear Science and Technology Organisation
5. Roger Smart
6 Matteo Altissimo, CSIRO Manufacturing & Infrastructure Technology
7. Michael W. Parker, Biota Structural Biology Laboratory and the ACRF Rational Drug Discovery Facility, St. Vincent's Institute of Medical Research
8. Stephen Best, School of Chemistry, University of Melbourne
9. Stephen Wilkins, CSIRO Manufacturing & Infrastructure Technology
10. Stacey Borg, CSIRO Exploration and Mining
11. Peter Lay, University of Sydney
12. Gill Duchesne, Jim Cramb and Professor Tomas Kron, Peter MacCallum Cancer Centre
13. Mike Lawrence, CSIRO Molecular and Health Technologies
14. Australasian College of Physical Scientists and Engineers in Medicine
15. David Cohen, Australian Nuclear Science and Technology Organisation
16. Australian Society for Microbiology
17. Chris Ryan
18. Ken Murrell, Department of Further Education, Employment, Science & Technology, South Australian Government
19. Sophie Betts, Department of State Development, Trade and Innovation, Queensland Government
20. David Parsons, Women's and Children's Hospital, Adelaide
21. Kerry Stanaway, Geological Society of New Zealand
22. Jenny Martin, Institute for Molecular Bioscience, University of Queensland
23. David Paterson, Australian Synchrotron Project, Major Projects Victoria
24. Andrea Gerson, University of South Australia
25. Gene Ice, Oak Ridge National Laboratory
26. Tim White, Nanyang Technological University
27. Kath Smith, President, Australian Microscopy and Microanalysis Society
28. Frank Larkins, International Scientific Advisory Committee, Australian Synchrotron
29. Linda Kristjanson, Brian O'Connor, Arie Van Riessen and Craig Buckley, Curtin University of Technology
30. Rob Lamb, Australian Synchrotron Research Program
31. Peter Colman, Walter and Eliza Hall Institute of Medical Research
32. Klaus-Dieter Liss, Australian Nuclear Science and Technology Organisation

appendix 5

ASRP facilities and access

The Photon Factory is a 2.5 GeV second-generation synchrotron light source in Japan. The Australian National Beamline Facility located at the Photon Factory is a multi-capability hard X-ray beamline. The primary instrument is a multi-configuration vacuum diffractometer which can be configured as a high speed X-ray powder diffraction camera or as a two-circle diffractometer, a triple-crystal diffractometer and a small angle scattering diffractometer. An optical table behind the diffractometer functions as a second experimental station, primarily used for X-ray absorption spectroscopy. The ASRP has complete scheduling and operational control over the ANBF.

The ANBF was initially funded by the Australian Government science department, the ARC, ANSTO, CSIRO, ANU, the University of NSW and the University of Sydney. In addition, LIEF funds were granted in 2003–04 for a new 36-element array detector for X-ray absorption experiments for the ANBF.

The Advanced Photon Source is the premier hard X-ray synchrotron research facility in the USA. The ASRP is a member of three of its beamline operating groups: the X-ray Operations and Research section (XOR) and the BioCARS and ChemMatCARS sectors of the Consortium for Advanced Radiation Sources (CARS).

- The ASRP is a partner in XOR with guaranteed access to beam time on three sectors (1, 2 and 4), with a beam time allocation of 5% on sectors 1 and 4, and 10% on Sector 2. ASRP users also have in-principal access to the other XOR-operated sectors, via the APS General User Proposal system. The ASRP provides travel funding to Australian users who gain access to any XOR sector using this system, to encourage increased use of XOR and enable access to its capabilities.

- BioCARS focuses on basic biological processes in structural terms while ChemMatCARS is dedicated primarily to static and dynamic condensed matter chemistry and materials science. The ASRP has contributed capital and operations funds to BioCARS and ChemMatCARS and in return is allocated 11% of beamtime at BioCARS and 17% of beamtime at ChemMatCARS. The ASRP contributes annually to the operation of BioCARS and ChemMatCARS.

The National Synchrotron Radiation Research Center is a 1.5 GeV third-generation synchrotron light source in Taiwan. The NSRRC's mission involves pioneering scientific research in the vacuum ultraviolet and soft X-ray spectral regions. Through the ASRP, Australian science and industry have access to the facility's 30-plus beamlines as well as two high-performance hard X-ray beam-lines in SPring8 (Japan's largest synchrotron facility) that are owned and run by the NSRRC.

The specifications for the ASRP soft X-ray system at the NSRRC were developed in consultation with potential users and suppliers. For example, the ability to keep a sample cold at liquid nitrogen temperatures throughout the entire system springs from the wish of a number of Australian groups to analyse volatile mineral samples: a particularly Australian problem. The result is unique for a synchrotron-based system of this type. The ASRP end-station and its support system have been designed to be used on any of seven soft X-ray beam-lines at the NSRRC. This instrument will be moved to the Australian Synchrotron after 2007.

As well as hosting scientists at the ANBF, the APS and NSRRC, the ASRP offers service crystallography for powder diffraction at the ANBF and small molecule crystallography at ChemMatCARS. Samples are transported to the overseas facilities and measured by experienced synchrotron scientists.

Access

ASRP beamline facilities are available to all Australian scientists. To ensure that access is based only on scientific excellence, travel and subsistence expenses are paid to research teams that are awarded time on the facilities. Proposals are refereed by independent Australian experts and beamline time is allocated by the ASRP Specialist Committee for each facility. In line with international best practice, proposals are reviewed against the following criteria:

- The scientific merit of the proposed research
- The need for synchrotron radiation techniques
- The track record of the investigating team
- Technical feasibility

Additional weight is given to proposals from investigators new to synchrotron radiation and those involving PhD student training, as part of expanding the user base and domestic synchrotron skills base. The ASRP actively encourages new user groups to submit proposals.

The ASRP's Research Fellowship Scheme aims to attract outstanding Australian scientists to areas of research that involve either the use of established synchrotron radiation techniques to solve important problems or the development of synchrotron radiation techniques or instrumentation. The scheme's selection criteria specifically allow for industrially oriented research. The Fellowships are fully funded by ASRP members and are awarded on a competitive basis. Fellowships are reserved for applicants proposing to work at one of the ASRP member organisations. The scheme is increasing the number of synchrotron-literate scientists who will be capable of contributing to the use, operation and management of the Australian Synchrotron.

Intellectual property developed by users of ASRP facilities remains the property of the user's institution, which encourages commercialisation.

appendix 6

Memoranda of Understanding

As at April 2007, the Australian Synchrotron had the following MoUs in place:

1. SPring8, Japan
2. Advanced Photon Source, USA
3. European Synchrotron Research Facility, France
4. Swiss Light Source
5. Photon Factory, Japan
6. Diamond Light Source, UK
7. Beijing Synchrotron Radiation Facility, China
8. Canadian Light Source
9. Shanghai Synchrotron Radiation Facility, China
10. Pohang Accelerator Laboratory, South Korea

More MoUs will be negotiated.

The Australian Synchrotron Research Program has the following agreements to support its activities:

1. Advanced Photon Source, USA (MoU and both Proprietary and Non-Proprietary User Agreements)
2. Photon Factory, Japan (MoU and agreement)
3. NSRRC (MoU)
4. University of Chicago (Articles of Agreement)

appendix 7

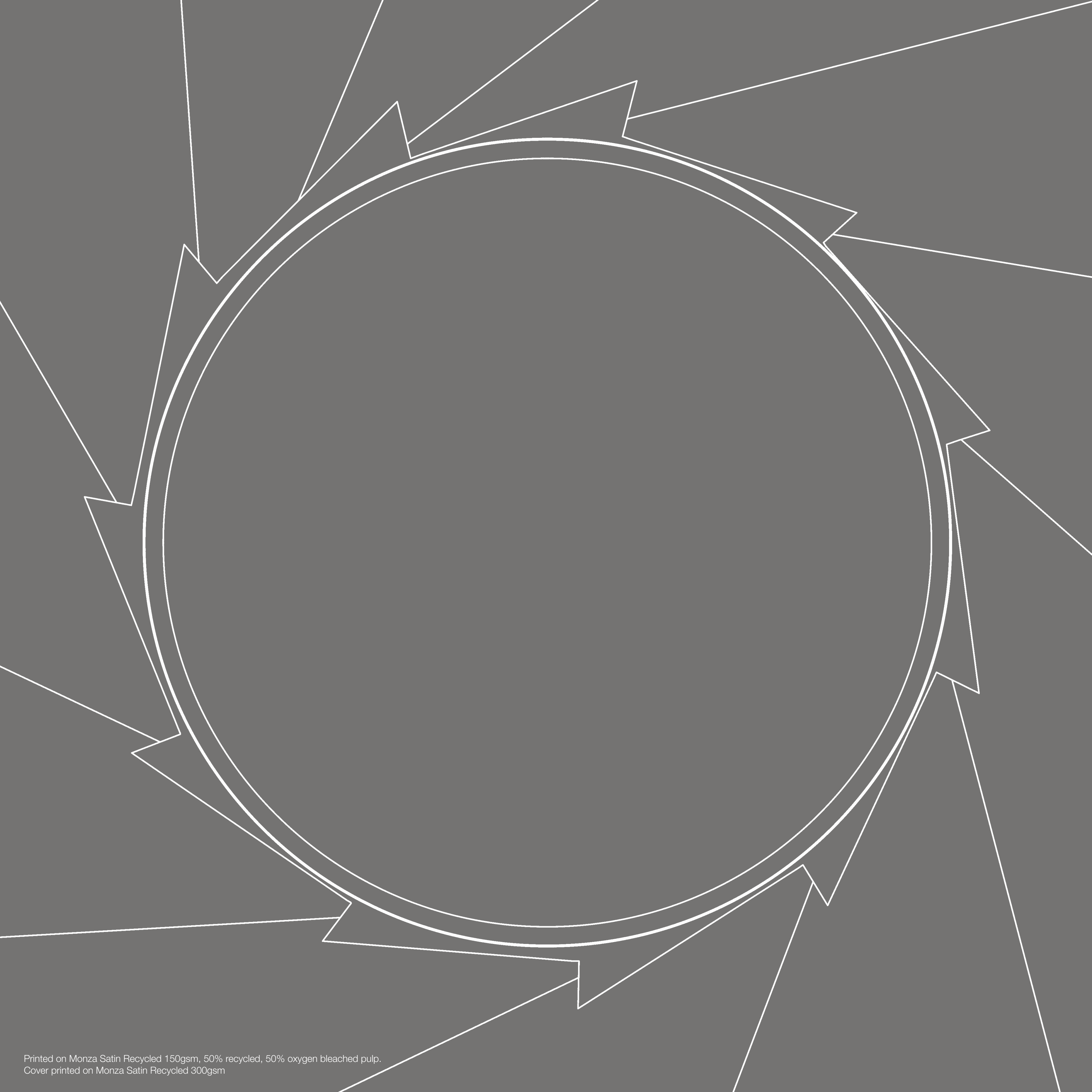
Growth planning process

The steps in decision-making by the decadal planning committee in setting the plan for growth are as follows:

1. Seek input from the community and committee members on their perception of future needs for Australian synchrotron-based science.
2. Analyse the community's input to identify a suite of capabilities.
3. Agree on bases of priorities and their weightings.
4. Assign a score from 1–5 for each capability against each priority base.
5. Rank-order according to the weighted score.
6. Assess the result against the balance of scientific, community and industrial needs and make adjustments as appropriate.
7. Release the priority-setting process to the community along with the arguments for any adjustments arising from step 5.
8. Accept further input and commentary from the community.
9. Go back to step 3 and re-assess whether scores are appropriate in the light of community input.
10. Repeat steps 4–6.
11. Finalise.

glossary

AINSE	Australian Institute of Nuclear Science and Engineering
AMRFP	Access to Major Research Facilities Program
ANBF	Australian National Beamline Facility
ANSTO	Australian Nuclear Science and Technology Organisation
ANU	Australian National University
AOF	Asia–Oceania Forum
APS	Advanced Photon Source
ARC	Australian Research Council
ASRP	Australian Synchrotron Research Program
CARS	Consortium for Advanced Radiation Sources
CD	circular dichroism
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CT	computed tomography
CXS	Coherent X-ray Science
ESRF	European Synchrotron Research Facility
FEL	free electron laser
FTIR	Fourier-transform infra-red
IP	intellectual property
IR	infra-red
LIEF	Linkage Infrastructure, Equipment and Facilities
LIGA	lithography, electroforming and moulding (German acronym)
MNRF	Major National Research Facilities
MoU	Memorandum of Understanding
NCRIS	National Collaborative Research Infrastructure Strategy
NRP	National Research Priority
NSAC	National Science Advisory Committee
NSC	National Science Case for the Initial Suite of Beamlines
NSRRC	National Synchrotron Radiation Research Center
NSW	New South Wales
PC	physical containment
PDF	pair distribution function
PEEM	photoemission electron microscopy
PX	protein crystallography
R&D	research and development
RIAG	Research Infrastructure Advisory Group
RIXS	resonant inelastic X-ray scattering
QXAS	quick-scanning X-ray absorption structure
SANS	small angle neutron scattering
SAXS	small angle X-ray scattering
SMX	small molecule crystallography
STXM	scanning transmission X-ray microscopy
TEDDI	tomographic energy-dispersive diffraction imaging
THz	tera hertz
USAXS	ultra small angle X-ray scattering
UV	ultraviolet
VUV	vacuum ultraviolet
XAS	X-ray absorption spectroscopy
XFEL	X-ray free-electron laser
XOR	X-ray Operations and Research section
XRD	X-ray diffraction
XRF	X-ray fluorescence
XRM	X-ray microscopy
3D	three-dimensional
2D	two-dimensional



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