Securing and synergizing photon- and neutron-based science and innovation

A national strategy in Norway for utilization of international large-scale infrastructures for photons and neutrons

Foreword

This document “A national strategy in Norway for utilization of international large-scale infrastructures for photons and neutrons” is a result of work carried out by representatives from the main institutions applying synchrotron and neutron based methodologies in their research and education programmes. The representatives were appointed by their respective home institutions (UiO, NTNU, UiB, UiT, UiS, IFE, SINTEF and NGU).

The appointed working group analyzed the status in Norway within synchrotron/photon and neutron based research, as summarized in the document “ståstedsanalyse”. In this process, which relates to 2020-22, webinars were arranged with users, interested scientists and national and international experts. This resulted in recommendations as agreed by a broad user community. This 2021/22 analysis is now updated with a short summary, which however, is not based on any additional surveys, and may therefore be incomplete.

The appointed steering group has interacted closely with the working group with the goal to arrive at recommendations that align with strategies and viewpoints of the entire community in Norway. Finally, draft documents were sent to all key institutions (UiA and NMBU in addition to those mentioned above) and detailed response was received from three institutions. The steering committee has carefully considered the received suggestions and modified the strategy document accordingly.

This strategy is based on the views and recommendations of users at the research institutions, in an open process with opportunities for all users and other stakeholders to join and suggest. The Research Council of Norway (RCN) has not been active part of the work and has requested that the process was run as a joint effort between the research institutions. Some recommendations and paragraphs should be read in this perspective. Finally, this strategy document does not include an action plan, neither at the RCN nor at the institution level. It is however our clear hope that this strategy will initiate concrete processes between the funding and the research institutions and finally agree on concrete action plans.

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October 28th. 2024

Executive summary

International large-scale infrastructures for photons (such as X-rays) and neutrons are the modern spearheads for cutting-edge studies of soft and hard materials and associated phenomena across a wide range of areas, driving technological developments to solve societal. challenges and generating novel insights. Examples include structure and function of the SARS-CoV-2 virus, "live" studies of battery electrodes, atomistic insights for complex catalytic systems, studies of spin-orbit coupling in materials for quantum computing, among many others. This strategy document outlines how Norwegian institutions and research communities should act to take best advantage of such infrastructures.

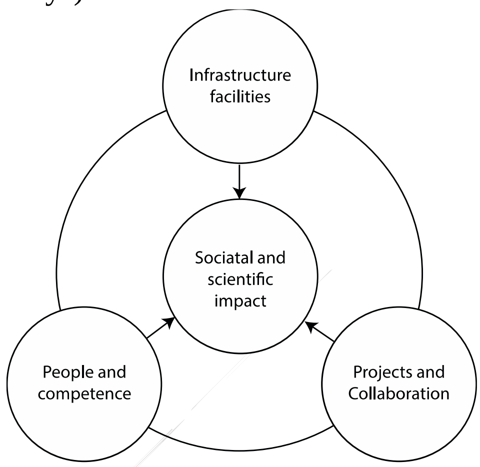

Figure 1: Societal and scientific impact

The overriding ambition of the strategy is to advance Norwegian science and innovation, Figure 1. This document delineates individual goals and recommendations for best use of international large-scale photon and neutron infrastructures and related actions over the next 10 years.

Overall goals (status achieved after appropriate actions):

- Scientists in Norway have adequate resources for high-quality research in home laboratories as well as good access to beam time at large-scale facilities, for which Norway maintains commitments (ESRF, ESS, SINQ and SNBL), or at which access is currently provided via research proposals.
- Regarding the European Spallation Source (ESS), an adequate user community has been established and is able to make good use of neutrons in high-level research projects.
- Strong ties to strategically important international photon and neutron infrastructures are maintained, and bottom-up processes for proposing new connections are active.
- Cutting-edge techniques available at international photon and neutron infrastructures are routinely used in research and innovation projects by Norwegian scientists from academia, research institutions and industry.
- The national user community is well coordinated, promotes competence building at Norwegian institutions and is known for top internationally competitive expertise.
- International large-scale facilities are seen as important tools to help solving research issues of high societal importance, including innovation in partnership with industrial actors.
- A solid involvement of Norwegian companies is realized through R&D collaborations.

Recommendations (for details, see main document)

- Align institutional and national funding mechanisms to ensure continuity for long-term development of competence and scientific excellence:
    - Stimulate/prioritise the use of international photon and neutron infrastructures to increase quality in science and innovation.
    - Establish funding mechanisms for long-term international collaborations on methods and infrastructure development, as well on competence building at home institutions.

  - Assure sufficient funding for effective fundamental scientific research in prioritized research areas, maintaining high levels of capacity (human resources), quality (competence building), and home laboratory instrumentation (infrastructure).
  - Provide funding for secondment of staff and coworkers, and for co-funding PhD and/or Post-doc positions at international facilities.
- Create an appropriately funded Norwegian user organization that:
  - Communicates opportunities offered by international photon and neutron infrastructures and provides guidance to national users.
  - Coordinates networking and competence-building activities for photon and neutron relevant science and innovation in Norway.
- Align infrastructure road maps to:
  - Strengthen, evaluate and develop benefits from commitments in partnerships with large-scale facilities and their connection to relevant national infrastructures.
  - Position scientists in Norway to compete for access to international photon and neutron infrastructures based on scientific merits.
  - Evaluate and promote new partnerships or access modes to international facilities with methods/fields deemed strategically important for the Norwegian science community.

About this document

This strategy document has been developed by a working group in an open process, whereby we have collected input from the active user community groups through a survey and two webinars[1]. A steering group with members from the main research organizations provided continuous input and contributed to the final report. The report was circulated to the relevant research institutions for final criticisms and suggestions. The working/steering group met, discussed, and agreed on how to incorporate the received suggestions into the final version of this document.

The first step in the process with this strategy was to summarize the status of the user community and its development during the last 10 years in a report[1].This provided the basis to analyse trends and identify opportunities for future development.[1] The strategy thus represents the collected interests and concerns of the key actors within the fields in Norway. It aims to secure and advance the capabilities and productivity in the relevant Norwegian communities with respect to scientific output, education and interdisciplinary integration of activities.

[1] Se ståstedsanalysen

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Importance of Photon- and Neutron-based Science

-Facilities are needed at multiple levels of research

The development of new generations of photon and neutron sources during the last three decades has radically transformed the capabilities of experimental investigations of material properties (hard and soft condensed matter) with respect to length scales (macroscopic and nanoscopic), time domains (into femtosecond regimes), energy ranges (near absolute zero temperatures to terawatt powers), and not least, throughput. The most advanced investigations based on photons and neutrons, representing ("cutting-edge") state-of-the-art science, are now conducted using methodologies available only at large-scale infrastructures[2]. But even investigations that are conducted quite routinely may require ready access to such infrastructures. This diversity of needs is consistent with Norwegian membership in some infrastructures, while Norwegian scientists regularly visit even several more[3].

-Investments are justified by "value chains"

Governments around the world invest heavily[4] in research infrastructures to access fundamentally new science and to build fundamentally new technical competencies, available for application to projects of highest societal and technological priorities. At the national level, this implies that questions and problems are identified in local laboratories and in research groups, but also in industries where research is integrated with innovation. The strongest proposals and visions will integrate competence and diversity of strong home laboratories with the best data acquisition at photon and neutron sources. This provides the basis for a broader research community that links education, creativity, project initiation, innovation, and commercialization across universities, research institutions, and industry. In order to take full advantage of large-scale infrastructures, Norway needs a coherent strategy on how to build and support the entire value-chain of priorities.

The need for a Strategy

-A strategy will best align infrastructure use with specific Norwegian research priorities

The long-term plan for Norwegian research[5] prioritizes specific areas of greatest need and value. Norwegian use of infrastructures for photons and neutrons currently impacts the value chains that are at the core of five out of the six thematically prioritised areas. We illustrate this below (see Figures 2, 3, 4, 6, 7) using brief examples from each of these five areas: *Sea and coast*, *Health*, *Climate, environment and energy*, *Enabling and industrial technologies*, and *Societal security and preparedness*. The value chain perspective makes clear that a strategy for best use of large-scale infrastructures must consider the global context. Norwegian scientists (including basic, applied, and industry researchers) must not only have access, but also sufficient expertise and capacity to use the various international research infrastructures effectively. This report aims to promote good management of national resources as part of productive coordination with international facilities. Note, that such access is often a prerequisite for world-lead science. This implies that any strategy, pointing at disciplines and technology areas, should be naturally integrated into ambitious strategies for fundamental and application oriented basic science in Norway. This is currently lacking and hence a most important joint task for institutions, RCN, ministries and industrial locomotives.

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[2] Synchrotrons or free-electron lasers for photons, and reactors or spallation sources for neutrons.
[3] Se ståstedsanalysen
[4] Typically a large scale infrastructure is an investment in the order of 2-30 billion NOK.
[5] Meld. St. 5 (2022–2023), Langtidsplan for forskning og høyere utdanning 2023–2032 https://www.regjeringen.no/no/dokumenter/meld.-st.-5-20222023/id2931400/

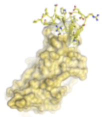
Scientific area		Basic research	Applied research	Innovation
Structural Biology		Disease Origins	Therapeutic Principles	Medicines Vaccines

*Figure 2 - **Health**: the unprecedented speed of vaccine and therapy development in response to the coronavirus epidemic dramatically illustrated the value chain for synchrotron dependent structural biology research. Crystal structures of virus components, determined* using synchrotron X-ray radiation, showed how the spike protein enables cell invasion (disease origin), how invasion may be blocked directly or by immune system activation (therapeutic principles), leading to vaccines and a variety of experimental therapies.

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-The strategy must coordinate a diversity of needs outside of the facilities

The large-scale infrastructures provide a multitude of diverse experimental techniques that can be applied to multiple fields of natural science. Each technique and area of application requires specialized expertise. This is evident in the currently diverse Norwegian user community. From the perspective of users and their research institutions, access to beam time is an obvious means to enable characterization of materials with state-of-the-art methods. However, concentrating on access alone may distract from other needs for conducting state-of-the-art research, now and in the future. One key area is training and transfer of expertise. The development of methods and applications into new scientific areas is now extremely rapid, yet they share many common denominators related to experiment, tools and analysis. Maintaining high levels of expertise will enable growth into areas emerging in the future. Another aspect is coordination of resources, and to bridge preliminary experiments and preparative work with physical access to international large-scale infrastructures. The underpinning science and preliminary work are keys for success with applications for access. A growing challenge is the handling the huge amounts of collected data (“big data”), as terabyte amounts of data is increasingly accompanying even individual experiments. Although this is already addressed directly at the large-scale facilities themselves, it must also be addressed at the level of the Norwegian stakeholders in a coordinated and future oriented way.

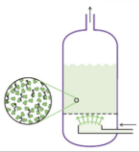
Scientific area		Basic research	Applied research	Innovation
Materials science		New compounds	Catalytic performance Sorption/desorption	Catalysts for abatement processes Sorbents for capture and recovery

*Figure 3 – example value chain for **Environment**: Catalyst development goes via new compounds and nanostructures. Key information needed are atomic scale descriptions of average and local crystal structures, valence state and local coordination. In addition, understanding of the dynamics in atomic arrangement and valence state during catalytic performance is important. Access to well-equipped home laboratories for X-ray diffraction and spectroscopy, and large-scale synchrotron radiation facilities to follow the dynamics in the materials stability, reconstruction and possible degradation processes is indispensable.*

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-The strategy involves diverse stakeholders

The group of stakeholders for which this strategy is conceived has grown during recent decades to become much larger than the core community of neutron and photon experimentalists. The science represents materials-based research in a broad sense, including basic and applied sciences in physics, chemistry, biology, pharmacy and medicine. The large-scale facility characterization, whether being molecules (e.g. bioactive molecules, drugs - fig 2), metals/ceramics (e.g. batteries - fig. 4), or other complex materials, depends on expertise and knowhow, and provides results that influence further development of large scientific programs, with ultimate impact on end users and innovation products. Many challenging scientific and technological issues can only be properly addressed via access to advanced international infrastructures. However, access is equally essential for exploring less cutting-edge aspects of materials and systems. In either case, the research programs are rooted in home laboratories and their links to national infrastructures. These fundamentally oriented early user environments are thus pivotal for the initiation and good progress of Norwegian prioritized thematic programs, and their research outcomes are associated with the respective value chains. Non-researcher stakeholders, such as end users of results or products, have an interest to communicate needs and priorities to the early user environments. Conversely, the latter stakeholders also have an interest for integration into dissemination of results.

-Current large-scale facility capabilities: user needs and costs co-determine strategy
Large-scale facilities enable detailed studies of a fundamental character and can provide ground-breaking new insights. However, they have also evolved to support applied research in multiple thematic areas, with some beam lines and sample environments specifically designed for efficient support of innovation and commercialization work. Individual experiments at large-scale facilities are expensive, with costs of around 10 kEuro per day as a reasonable average estimate. For facilities in which Norway or Norwegian institutions are either formal partners (ESRF, ESS) or bound by a collaboration agreement (SNBL, SINQ/NcNeutron) the averaged access cost can be estimated from table 1 – in total around 50 MNOK/year. This can be compared to Norway's largest commitment in international infrastructures, CERN, with a cost of 323 MNOK in 2024. The size of the involved user communities are very different, as evident from the huge number of synchrotron and neutron (SR/ND) users and user institutions.

Table 1: Currently funded infrastructures

Infrastructure	**Type of source**	**Type of funding**	**Funding period**	**Cost /year (estimate)**
ESRF	Hard X-ray	National budget	Long term	13 MNOK
SNBL	BM01/BM31@ESRF	National infrastructure	2021-2024	9 MNOK
ESS	Neutron	National budget	Construction phase (2014-2027) 2.5% 700 MNOK Operation 2027→	20-40 MNOK
SINQ (NcNeutron)	Neutron	National infrastructure	2016-2026	5 MNOK

The costs connected with specific experiments (except at ESRF) are covered by the users, often based on public funding, and in some cases with institutional contributions. For experiments at facilities without formal partnership contracts, that actively are used by Norwegian scientists, (see "ståstedsanalysen", costs with experiments are covered similarly by the users, however, access is managed in different ways. A common mechanism is to compete for cost-free access based on merit for open projects (patent-free results published in open literature and raw data being made available to the public). This model is valid for applied open projects as well. For proprietary research, beam time must be purchased at a cost consistent with EU rules. Most large-scale facilities provide opportunities for industrial beam time.

A cost-benefit analysis is an important basis for a strategy. However, the benefit values are impossible to quantify precisely and are difficult to estimate qualitatively, especially for academic output. Several measures may be considered, including cost per publication, cost per follow-up funding grant value, cost per trained student or scientist, cost per follow-up commercialization project, and so forth. Each of these outputs have unclear quantitative values that can be manipulated, so a strategy which defines output metrics must be made carefully and communicated clearly.

-Clarifying and prioritizing access modes is a core element of strategy
The statistics on the use of photon and neutron-based methods in Norway clearly demonstrates the need for continued member/partnerships, and for various access modes. Memberships are the main route for strategic participation, involving also development of techniques, and should be assessed

continuously. While the current situation appears satisfactory, there are certain memberships like the ESS for which there is an urgent need for a much stronger focus on establishing a solid research portfolio and robust user environments, ahead of the opening of the facility.

-Lack of coordinated funding and strategy creates several threats
It is vitally important to coordinate plans and strategies locally, nationally and internationally. There is a genuine worry that the communities are now at risk of losing opportunities due to inconsistent and fragmented funding and the lack of coherent strategies. One threat is to home laboratories with respect to instrumentation typically provided via infrastructure calls. Two threats arise from a lack of skill redundancy: irreversible loss of expertise with changing staff, and insufficient capacities for robust research. Finally, a lack of funding for research projects that train PhD students and other researchers also threatens adaptability to future research needs. For long term efficient exploitation of the large-scale photon and neutron facilities, these threats must be addressed, now. Recognizing that Norway will in the foreseeable future *not* be an owner or operator of a large-scale photon or neutron facility, a successful strategy should ensure that major amounts of beam time are awarded to Norwegian scientists at highly competitive international installations. This document describes a number of recommended measures to counter perceived threats and achieve a high level of success.

Scientific area	Basic research	Applied research	Innovation
Materials science	(New) compounds	Charging/de-charging Photovoltaic effect Sorption/desorption	Batteries Solar Cells H-storage materials

*Figure 4 – Example value chain for **Energy**: Battery development goes via new compounds and materials and their performance in an assembled battery. Key information needed are atomic scale descriptions of average and local crystal structures, valence state and local coordination. Followed by this, understanding of the dynamics in atomic arrangement and valence state during charging and de-charging as well as possible degradation mechanisms is essential. Access to well-equipped home laboratories for X-ray diffraction and spectroscopy, and large-scale synchrotron radiation facilities to follow the dynamics in the battery processes (charging/de-charging, degradation mechanisms) while the battery is in operation is indispensable.*

Ambitions and main actions for the next 10 years:

This strategy aims to ensure that Norway best harnesses international developments in neutron and photon technologies to advance its own science in areas of most critical societal knowledge needs. To create an overview and approach this comprehensively, we identify three qualitatively distinct areas of analysis (“pillars”):

- *People/competence*: using, transferring, and expanding knowledge and skills
- *Facilities and infrastructures*: enabling these skills and the knowledge to be used
- *Projects*: bringing the people, skillsets, and facilities into solving essential problems

These are illustrated in Figure 5. At the left, the international infrastructures are the spearhead of a research value hierarchy, that includes local and national infrastructures as essential prerequisites. People and their competencies are represented in the middle. Grouped according to interests and expertise, the needs for appropriate networking become clear. This networking facilitates dynamic changes such as training and mobility between different groups, correlated with expertise and dissemination throughout the Norwegian science and innovation communities. At right we depict funding instruments and their focus fields which guide how researchers choose which facilities to use for successful project completion and also guide how training may be organized.

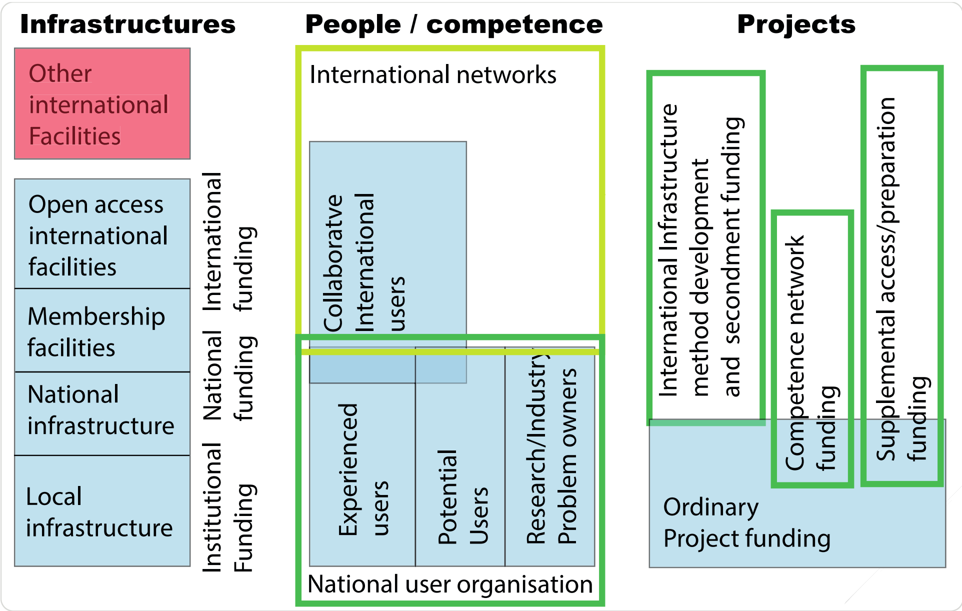


Figure 5: Illustration of the three identified pillars important for the effective use of international photon and neutron infrastructures.

All three pillars are essential. Project funding and organization are necessary to initiate any activity, and individual projects currently depend almost fully on external grants. Funding must also maintain a strong research base at the institutions to be able to identify the scientific needs and plan projects, and people need funding for continuity of work and experience using large facilities. Coordinated planning should provide for access and presence at the international facilities for preliminary work, training, and network building, as well for sample preparation and characterization at local or national infrastructure levels, to ensure long-term continuity of expertise and core activities at various facilities.

Although the size of the user community and its breadth of activities appear to be in good shape, along with good access to various synchrotron and neutron facilities via formal agreements or open proposals, an overall scientific strategy for Norwegian/institutional involvement is lacking. Many possibilities offered by large facilities are not yet seen as cornerstones in Norwegian strategies on basic research or in connection with prioritized issues (themes) of high societal importance.

Comprehensive use of advanced large-scale facilities is a prerequisite for Norwegian research and innovation within areas of natural and applied science to maintain at an international top level. The responsibility for bringing opportunities into activities must be shared between the users (the hands and brains), the institutions (responsible for science and education/training) and the funding and strategy responsible bodies (Research Council of Norway, and the Ministries),

In a ten-year period, the ambition is to have reached the following levels:

People/competence

The Norwegian user community has a structure, critical mass and international connections that enable addressing scientific problems with a multitude of state-of-the-art techniques. Strong competence networks are established on common techniques within a user organisation that works to promote coordination of activities across the scientific disciplines, facilitates user training, and stimulates innovation with industry partnerships. Through these networks, diverse research groups and technologies have a well-functioning national communication platform. A good number of Norwegian PhDs/post docs are affiliated with large scale facilities, establish expertise, and are typically part of collective projects where methodology is shared but science is diverse covering different topical fields.

This acts as a model to assure rapid and efficient knowledge transfer in areas where development is fast and traditional outreach is not adequate.

Scientific area		Basic research	Applied research	Innovation
Marine bioprospecting (Structural biology, Structural chemistry, catalysis)		New compound structures	Novel drug leads Novel antimicrobials Novel enzyme activities	New medicines Marine antifoulants Industrial enzymes

Figure 6 – Example value chain for ***Sea and Coast***: Bioprospecting in marine environments provides access to untapped chemical diversity and great promise for the discovery of novel compounds and activities. Microbes and other marine organisms have evolved highly diverse and specialized small molecules as defence and signalling mechanisms. Marine extreme environments (cold, heat, salt) have driven the adaptation of enzymes to extreme conditions. These novel compounds, large and small, may be optimized for innovative applications by structure based design approaches.

Infrastructure

All research communities, whether thematic or technique oriented, have (proposal based) access to infrastructures required to obtain cutting-edge results within science and innovation. Norway is a committed long-term partner in international facilities, infrastructures, and networks at a level comparable to other Nordic countries. Norway-based scientists and companies have the necessary access to local and national infrastructures and networks, forming a basis for proposals and use of international large-scale infrastructures. Within selected areas, Norwegian scientists utilize methods development at state-of-the-art international infrastructures as a vehicle to reach the forefront of scientific development and innovation. The Norwegian users are well organized to take best access modes into use; these comprise for instance BAG (block allocation group) proposals or HUB [6] activities that are established on thematic topics (like the battery HUB at ESRF).

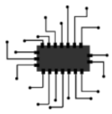
Scientific area		Basic research	Applied research	Innovation
Safe, low energy monitoring communic.		Material physics and chemistry	New device conceps: Sensing, storage and Communication	Low energy devices Quantum sensing and communication

Figure 7 – Example value chain for ***Societal security and preparedness***: Development of improved secure communication, energy efficient computing for analysis and sensing for societally important areas like analysis of the environment is made through understanding and utilising fundamental properties of materials. Better sensitivity and less energy consumption is based on understanding quantum/chemical properties. Here, structural properties (X-ray and neutron scattering) must be coupled to electronic properties (synchrotron-based spectroscopy) magnetic properties (neutron-based spectroscopy) as well as understanding dynamics (time resolved spectroscopy). During a development phase, device monitoring and failure analysis is often dependent on synchrotron-based development.

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Projects and collaboration

The Norwegian institutional and national research strategies clearly address how large-scale photon and neutron infrastructures shall contribute to quality and capacity in research and innovation at the national level, in short and long terms. Application oriented research by academia and by Norwegian companies benefit from possibilities offered by state-of-the-art neutron and photon infrastructures. This is catalysed and promoted by a strong Norwegian scientific community.

For bringing people, facilities/infrastructure and projects closer together, recommended actions are:

[6] A HUB proposal is a community access proposal grouping together a number of independent Principal Investigators (PIs) working in the same major scientific field of high societal relevance, who commit to collaborate to coordinate the beamtime use and share results obtained in such a way that progress is faster and more impactful across the field.

- Create an appropriately funded Norwegian user organization along with strong competence networks that connect communities to create critical masses within sub-areas with ability to reach out to industry and other problem owners / potential users. Assure a corresponding coordination within the main institutions for synchrotron-/neutron-based research.
- Enable the user community to involve in international user organisations, events, schools and workshops at international facilities, and thereby connect to the international community. Establish a funding scheme for covering or sponsoring such participation.
- Likewise, assure secondments and a substantial number of early-career scientists working at and/or being affiliated with such facilities.
- Align local and national infrastructure road maps with the strategic planning of competence networks and with various modes for membership/participation at large scale facilities.
- Ensure that institutional and national funding mechanisms create the necessary scientific and methodological basis for research and innovation activities along the full value chains. Create means for competence building, methods development and long-term international interactions of the competence networks.
- Support users that have been granted competitive beam time with funding for travel and accommodation, in particular, in cases where the large-scale facility has no support program. A fair sharing of costs between home institution, RCN, and the user/group seems reasonable.

Concretely, in order to rapidly kick off required actions, we suggest:

- ➢ A steering group is appointed by the institutions to agree on how to establish a properly funded Norwegian user organization, in coordination with Norwegian users and key funding agencies, and to formulate this in a MOU. The success but also shortcomings of organisations like NORSCATT, NONSA as well as the Danish DANSCATT may act as guidance for how to set up an organization in line with Norwegian needs/interests. Target: the new user organization is established during 2025.
- ➢ The user organization obtains funding from the member institutions and the RCN, based on visions and foreseen activities/roles of the organization. Fees might be appropriate for participation at seminars, workshops, schools – if not funded directly.
- ➢ A working group is established with mandate to meet with user communities in order to identify a basis (scientific case) for possible future formal involvements with facilities of high importance for the community. The subsequent follow-up should be handled by the new user organization in understanding with the research institutions. This should eventually lead to proposals to calls in the RCN infrastructure programs.
- ➢ Based on surveys and foreseen developments, the new user organization should immediately put efforts into identifying fields of relevance for competence networks and discuss how these networks ought to focus with respect to instrumentation, methodology, science. There should be due focus on methodologies of relevance for various disciplines and technologies, with examples on how the continuous developments at large scale facilities in general open opportunities for all categories of natural science.

Main changes during the last ten-year period in Norway

One aim of this document is to advise stakeholders on how to enable the Norwegian research and innovation system to utilize international photon and neutron sources in an effective manner over the next 10 years. In this context, a short analysis of the status and the development during the last 10 years is useful. During this period, the user community has developed strongly:

People/competence:

Organized access to large-scale facilities becomes essential for many large user groups. The main competence in Norway is now held by a growing number of 50-70 staff at universities and in the institute sector. For synchrotron users, this indicates a doubling compared to 2009, however, it is unclear if this growth is in experienced or more occasional users. Based on a (continuous) Nordic analysis of the situation in the Nordic countries it appears that the core community of Norwegian neutron users, activities and publications have stayed at a constant level during the last 10 years. In sum, these staff employees — and some students — have been initiators of projects and beam-time applications that have provided important results for roughly 200-300 users in total, including PhD-students and post docs over a 5 year period.

Overall, the above positive development has occurred despite the lack of a well-coordinated user community and a national strategy. Notable exceptions are the structural biology community and to some extent the ESRF/SNBL users, where interactions have boosted scientific activity and quality within the respective communities. Locally, success is often coupled to local infrastructure investments that are well synchronized with utilization of international facilities. When studying the transfer of competence in different environments, we note that development of expertise is confined to relatively few locations, and that training opportunities for students are made at the local level, mostly through (externally funded) projects. There are currently no cross-institutional training programs specifically in photon and neutron science.

Facilities and infrastructures

Currently, the Norwegian research system has contracts regarding four running large-scale facilities or beam lines. The membership at ESRF, along with a Norwegian involvement in the CRG (collaborating research group) beamlines SNBL (Swiss Norwegian Beam Lines), has provided access and beam time since 1994. Within this context, Norwegian researchers have participated in the ESRF upgrade and the extension of the SNBL. Nationally, the JEEP II research reactor at IFE provided beam time to the user community since the sixties – however, the planned upgrade in terms of the funded NcNeutron national infrastructure became impossible owing to the sudden shutdown of the reactor and has instead been transferred and coordinated via collaboration with SINQ at PSI, Switzerland. Beam time has been provided to Norwegian users since 2021. The membership in ESS has not yet reached a state where ESS can provide neutrons for experiments, and the user program is expected to start first in 2027. In sum, these investments are major, and in particular ESS is very costly. The ESS is foreseen to govern wide areas of natural science.

During the same 10-year period, the investments into related and modern home-laboratories have increased significantly through the national research infrastructure program. As described above, the national neutron infrastructure turned international with the closure of JEEP II.

ESRF is the world-leading synchrotron and provides great opportunities for Norwegian science. The Norwegian scientific outcome from ESRF and SNBL, and recently of SINQ, is excellent and the user community of these facilities strongly advises continuation. In this respect, it is important to recognize that many users do their experiments and excellent research at other international facilities, due to either lack of access, lack of adequate or optimized instrumentation, scientific collaborations and more. Examples of these are: Hard-X-rays: DIAMOND, MAX-IV, PETRA, APS, SPRING-8 …. Soft X-rays: DIAMOND, SOLEIL, BESSY, MAX-IV, ELLETRA, NSLS, …. Neutrons: FRM-II, ISIS, ORNL, SNS, ILL, J-PARC, ANSTO, NIST….

The involvement in international facilities reflects the main strong-holds and drivers for the relevant type of science. However, this does not imply that the current formal arrangements cover all needs of

Norwegian users. The lack of more such involvements has multiple reasons; lack of coordinated actions by the users, lack of bottom-up initiatives supported at higher levels in the home institutions, lack of formal basis for possibly entering into binding contracts with an international institution, failing in RCN infrastructure applications, the budget envelope, the size of the user communities, and more.

Projects and collaboration

There have been significant changes in the funding mechanisms of the Research Council of Norway, with less calls on fundamental researcher projects connected to thematic areas, and an increasingly more narrow path for open research projects. One specific change is the transfer of the SYNKNØYT funding into Nano2021, which in turn is further modified by a fully different funding structure. Earlier, these schemes provided funding for securing and optimizing the Norwegian use of international infrastructures, with a focus on either infrastructure (Nasjonal satsning på infrastruktur) or on science within thematic programmes. Currently, for the thematic programmes, no dedicated efforts on the use or on prioritization of utilizing international infrastructures for photon or neutron-based science can be found in the portfolio plans [naturvitenskap (natural sciences), livsvitenskap (life sciences) og muliggjørende teknologier (enabling technologies)]. The user organization, NORSCATT, established in 2017, has not developed as foreseen and is currently not in operation.

Main challenges during the next 10-year period:

The main changes/challenges that can be foreseen for the next 10-year period are:

- Competence development and interaction with international facilities may not be in line with current and future needs of the Norwegian society due to low flexibility and/or inadequate perspectives and foresight in the Norwegian research/funding system
- Norway may fail to develop the existing connections to support and further strengthen links to strong internationally relevant communities
- The standardization/development in acquisition control, methods for data sharing and data analysis will take a large leap though rapid development of experiment control, massive data analysis and machine learning methods. The demand on effectiveness and science with low carbon footprint (less travel) will put pressure on the large-scale facilities and the user communities to work effectively and collectively, utilising altered methods for access
- The upgrades, commissioning and closing of several infrastructures will lead to further specialization, but then with improved capabilities. The availability of general-purpose beam time will most likely go down, which in turn may result in a more advanced and possibly more collaborative entry level for experiments
- For Norway, the start of user operation at ESS, that represents a massive investment, requires follow-up actions on several levels related to competence, capacity and collaborations.

People/competence:

The user community in Norway must be strengthened in order to connect local competence with national and international competence. The same holds for becoming able to establish close links to problem owners in science as well as in industry and innovation. This critical aspect, on capacity and competence, can only be solved by assuring an appropriate level of funding for basic research. Thereby one may foresee development of platforms of expertise at (key) institutions. These should in turn provide a foundation for application oriented and innovation-based projects.

The Norwegian contribution of 2.5% to the investments of ESS-ERIC, and the foreseen contribution to the future operational expenses, represents a mismatch with respect to the efforts that are invested in building competence, quality and capacity in neutron-based science. The ESS investment is indeed the largest Norwegian investment in materials-based science during many decades, probably ever. Any local or national response in terms of strategic positions that can help realizing this opportunity has not yet been expressed by universities or research institutions. In a similar manner, the Norwegian user community has not yet taken X-ray free electron lasers into routine use. Recently compact small scale neutron sources are being developed, with a potential for low flux experiments and competence building. This could be an opportunity also in Norway, given adequate sources being accessible and that this is requested by a sufficiently large and dedicated user community – in infrastructure proposals.

The Norwegian community should take part in developing new tools for measuring/access (common control software, common experimental platforms) and data analysis (massive parallel data analysis, machine learning). It should actively take part in developing research arenas of interest and interact with user organizations and the international scientific community. The challenge and opportunity is at several levels:

- Formal and informal connections with appropriate international user communities
- Development and training with respect to data processing and experimental planning and execution as well as undertaking data processing and analysis in local user communities.
- Strengthening the representation and participation in the international user organisations such as ENSA (European Neutron Scattering Association) and ESUO (European Synchrotron and FEL Users Organisation).

Facilities and infrastructures

A general challenge is that Norway must connect to the most appropriate facilities that are and will be part of our value chains. Although the larger picture seems good for the users of ESRF (all public beam lines plus public access to CRGs) and SNBL, there are specific weak points that needs to be addressed;

- In order to build required capacity and competence for good use of the highly costly ESS-ERIC, continuous interactions with large scale neutron facilities must be strongly supported, by personnel and projects, with access being based on competitive proposals. The current access mode and instruments at SINQ/PSI through NcNeutron serves to some extent this purpose for the aspiring community, however, proposal-based access to neutron facilities world-wide remains essential.
- For soft X-ray experiments all access for Norwegian users is currently proposal based. Attempts to achieve RCN infrastructure funding has so far failed. The user community and the relevant institution are strongly urged to develop concrete plans and actions for better securing adequate access in the future to this important field.
- Today, a number of cross-facility thematically oriented access schemes are being developed. It is important to secure memberships/usage of these developing opportunities. This also holds for development of cross-disciplinary research, where experts from different disciplines team up to address and solve complex questions by means of several SR/ND-based methods.
- The further development of national and local infrastructures should take place in phase with the international facilities. This includes more specifically, seamlessly making use of standardised set-ups for environment control, analysis and control software and data storage.
- During coming years, several large-scale facilities will undergo major upgrade programs. This will typically allow even more advanced/complex experiments. However, this may probably lead to a reduction in capacity for standard experiments, which indeed could cause access issues for a part of the Norwegian user community.

- Collaborations with beam line scientists at large scale facilities should be encouraged, including development of new set-ups that widens experimental opportunities. Secondment of PhDs and/or post doctors may provide benefits to Norwegian users in terms of beam time, user support and training programs.

Projects and collaboration

For Norway to be at the forefront, project funding towards long-term collaborative and development projects is needed. Mechanisms must stimulate new opportunities and developments that will help us explore future main value chains of the Norwegian society. Typical important gaps to be closed are:

- Funding for international infrastructure development and interaction, such as secondment
- National competence network funding; workshops and schools
- Supplemental access/preparation funding that enables access to highly specialized beamlines
- Funding of basic capacity and competence building
- Funding of application-oriented projects utilising photon and neutron-based methods, in particularly in fields of high social importance, but not limited to just those.
- Funding of projects (and meeting places) where universities, research institutes and industry together identify themes of common interest and where the use of large-scale synchrotron or neutron facilities is required, with the goal that beam time and new insight will emerge as a result of joint efforts.

Recommended actions to the main actors

The Government / Research Council needs to:

- Continouosly update of long-term participation/membership in international infrastructures in the national infrastructure roadmap
- Continuously analyse the prerequisites for access/membership to international infrastructures and actively utilise the Nordic and European arena for this
- Consider establishing an advisory group with key people, that are (i) representing Norway in international infrastructures and (ii) representing institutions; while assuring broad coverage of science fields and methodologies
- Establish appropriate funding mechanisms for long-term participation in international collaborations, including methods and infrastructure development. Consider re-launching a funding scheme like the earlier Synknøyt program
- Assure a solid portfolio of funding mechanisms / support programs that stimulates fundamental research in fields underpinning national priorities, to make sure that such research develops and uses the most adequate (advanced) tools at large scale facilities
- In general, stimulate to the use of international photon and neutron infrastructures in calls from RCN to help increasing the quality in relevant portfolios
- Assure adequate funding for thematic / prioritized areas to enable the user groups to hold the required expertise and capacity to utilize synchrotron/neutron-based methods, thereby enabling high quality and novel insight into fundamental and applied science.

The Universities / research institutes need to:

- Agree on a framework and contribute to funding of a national, interdisciplinary network in terms of a user organization
- Promote work of the user organisation to build long-term collaborations with industry and together adopt the funding mechanisms provided by the Research Council of Norway to build expertise and activity
- Integrate the use of international infrastructures into local strategies and roadmaps for research infrastructures. Consider and support bottom-up initiatives on new partnerships or memberships, interact with other research institutions and agree on strategies and actions.
- Assign responsibility within their organizations to create long-term relations with international facilities, for instance within a framework of competence nodes that include course participation, exchange, and secondment of staff to international research facilities
- Assure that photon and neutron science are included in relevant study programs and courses at all levels
- Support scientists to develop and maintain a required level of expertise in science and methods as a basis for solid use of large-scale SR/ND facilities. Have specific attention on competence building in perspective of ESS
- Provide mechanisms and reserve funding for secondment of staff as well for co-funding of PhD/Post-doc positions at international facilities. Seek co-funding from such facilities. Explore possibility to establish such a secondment program with RCN funding contributions.

The research community needs to:

- Activate a user organization with a part/full-time coordinator
- Enable cross-technology communication between potential users through networks, such as the user organisation, to help develop competence areas and coherent impact
- Discuss and evaluate, preferably in a bottom-up process by the new user organization, infrastructures for partnership, communicate with institutions and the RCN, with the goal to submit joint applications for national and local infrastructure membership and support.

- Make continuous competence and capacity gap analysis of the community
- Integrate users (stakeholders) from industry and the public sector into their user organization, and promote exchange of ideas on research
- Encourage development and use of suitable courses to PhD students and researchers (such as the Nordforsk-funded course for neutrons, HERCULES at ESRF, MAX IV Summer School and other)
- Set aside funds for experiments and participation at user meetings and schools in their budgets (proposals RCN and internally at the institutions) on equal basis as for other cost places. Clearly communicate the needs for such support to the funding agencies

The main actors take note of the recommended roadmap for infrastructure membership/partnership:

- Norway maintains membership in ESRF
- Norway maintains membership in ESS-ERIC
- The commitments in SNBL (at ESRF) and NcNeutron (at PSI) are maintained, currently as application-based national infrastructure commitments.
- Additional long-term strategic options for commitment should be considered
- The user community communicates and evaluates, preferably in a bottom-up process involving the new user organization, relevant infrastructures for partnership and promotes accordingly joint applications for national and local infrastructure support. For instance, an initiative on soft-X-ray would appear timely. Examples of current interest include
    - ILL (Neutrons)
    - MAX-IV (Hard/Soft X-ray)
    - XFEL (Time-resolution at femto-second timescale)
    - SLS (Swiss light source at PSI)
    - and more
- The user community maps out and evaluates membership in existing and future thematic frameworks for infrastructures, such as Instruct-ERIC (Infrastructure for structural biology)
- The user community identifies and clusters relevant national/local infrastructures and data analysis centers. These are then enabled to function as national hubs for competence building and interaction with international infrastructures. They will also support the user community in preparing proposals/experiments at large-scale facilities and performing efficient data analysis
- The tasks described for the user community are best handled in terms of a well organized and strong user organization