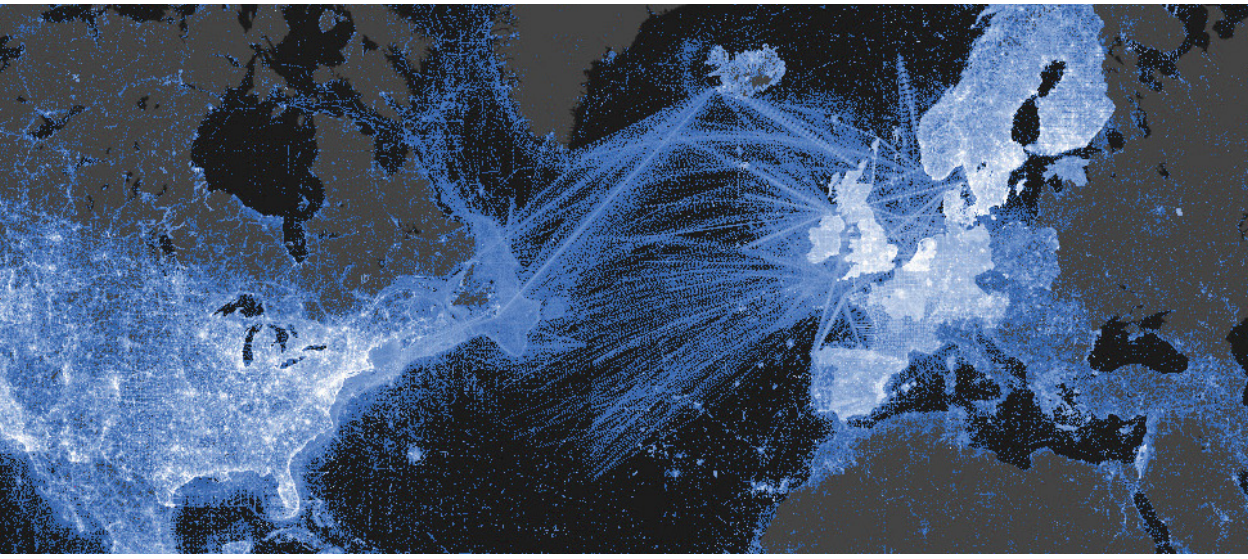
Vetenskapsrådet

THE SWEDISH RESEARCH COUNCIL'S GUIDE TO RESEARCH INFRASTRUCTURES 2014



Swedish Research Council 2015

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Swedish Research Council
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PREFACE

The Swedish Research Council's Guide to Infrastructures 2014 is part of the knowledge base compiled by the Swedish Research Council on which the Government can base its decisions regarding the upcoming Government Bill on Research Policy and its priorities within scientific councils, councils and committees. It can also be used as reference material in the research sector.

In 2014, the Board of the Swedish Research Council initiated a review of the processes involved in the prioritisation, financing and organisation of national research infrastructure. As a result, this revised guide is limited in terms of proposals for new infrastructure, and instead focuses mainly on the concentration and coordination of existing infrastructures, and on clarifying roles and principles for the future management of infrastructure. The 2016 version of the guide is expected to implement the new model for the Swedish Research Council's infrastructure management in full.

The international development, and the development in Sweden, has clarified the importance of specific roles and structures when it comes to prioritising infrastructure initiatives. Unlike individual research projects, there are relatively few infrastructure projects, but they are large in scale, costly, long-term and often require extensive coordination between organisations and disciplines. The shared financial responsibility between different stakeholders as proposed in the new model is expected to play a key role in achieving a clearer needs-based prioritisation, along with improved effectiveness and renewal. Infrastructure investments reflect the country's research policy profile, and it is therefore important for the Government and the Riksdag, research-funding bodies and universities, to have clear roles and a joint responsibility for strategic guidelines and for running and taking responsibility for Swedish research infrastructure interests.

In 2013, the Swedish Research Council commissioned an investigation into the academic need for e-infrastructure, i.e., resources for large-scale calculation, data management and storage. The investigation indicates that Sweden is in need of a national strategy for e-Science and e-infrastructure, which covers the entire research system. This fourth edition of the Swedish Research Council's Guide to Infrastructures will therefore have e-Science and e-infrastructure as a pervading theme.

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Secretary General of Research Infrastructures at the Swedish Research Council

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Chair of the Council for Research Infrastructures (RFI)

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SUMMARY

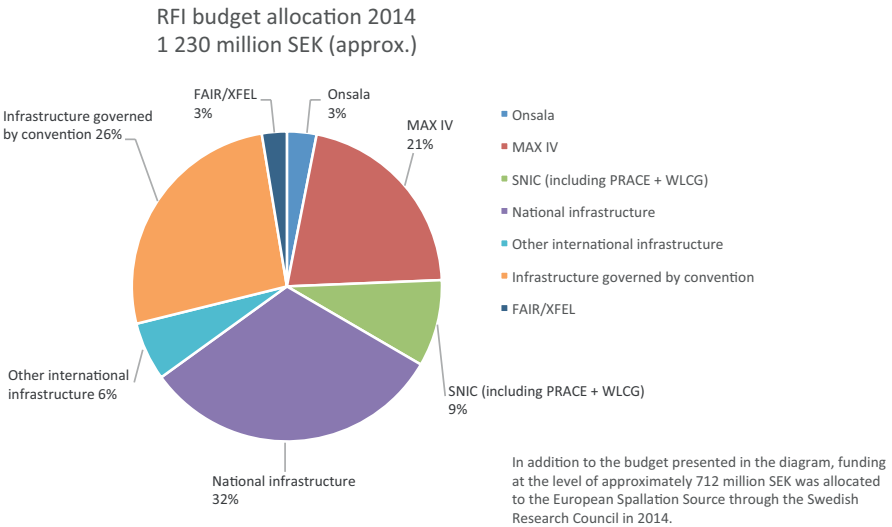
A balance needs to be struck, between sustainability and flexibility and between national and international infrastructure investments, in order to give Swedish researchers access to effective and high-quality tools. In 2014, the Swedish Research Council initiated a dialogue with Swedish higher education institutions on the review of the system for prioritising and funding of national research infrastructure, aimed at creating more sustainability and financial stability. This has resulted in the new model described in this report. In 2015, it will only be applied to national research infrastructure projects currently receiving funding from the Swedish Research Council. Prior to the 2016 update of the Swedish Research Council's Guide to Infrastructures, a broad survey will be undertaken to assess the needs for future research infrastructure investments. Due to the transition to the new prioritisation and funding model, the report only contains limited recommendations regarding new future investments.

This report contains seven subject-specific sections (Materials Science, Physics and Engineering Sciences, Energy Research, Environmental Sciences, Humanity, Culture and Society, Life Sciences and e-Sciences), with brief progress reports and descriptions of infrastructure financed by the Swedish Research Council in 2014, as well as examples of much needed future initiatives. The report contains examples of structural measures relating to the balance needed between research investments and research infrastructure investments. Furthermore, the examples relate to the importance of more outreach and training by infrastructures towards users, the capacity to motivate scientists to build and maintain infrastructures, as well as greater involvement for the Swedish industry in international research infrastructure cooperation and technological development.

The "Recommendations" section identifies specific areas where investments are needed. Particular reference is made to e-infrastructure, Swedish involvement in international (research) facilities and the coordination of distributed infrastructure in social sciences, medicine, life sciences and environmental sciences. Targeted calls for proposals within biological microscopy, mass spectrometry, and for databases in the fields of social sciences and medicine, have been envisaged for some time. This section also addresses how Sweden can best manage its role as host of the neutron scattering facility European Spallation Source (ESS), the synchrotron light facility MAX IV and the radar facility EISCAT-3D.

The aim of the recommendations is to make the use of Swedish research

infrastructure funding more efficiently and with a long-term perspective. Figure 1 shows a breakdown of the Swedish Research Council's total research infrastructure budget in 2014. The cumulative research infrastructure costs are expected to rise in Sweden between 2015 and 2020. This is in line with the trend in Europe and the rest of the world. Table 1 provides an estimate of known new investment needs (see page 14).



In addition to the budget presented in the diagram, funding at the level of approximately 712 million SEK was allocated to the European Spallation Source through the Swedish Research Council in 2014.

RECOMMENDATIONS

The recommendations are based on recurring themes from the area overviews, and highlight the structural measures and initiatives that should be most immediately prioritised. The recommendations are intended for the stakeholders who, together with the Swedish Research Council, shape the Swedish research system. The areas covered by the recommendations will be developed in the section "Tomorrow's challenges" and in the area overviews.

As of 2015, calls relating to infrastructures of national interest will be based on the prioritisations made in the Swedish Research Council's Guide to Infrastructures. The box below contains a summary of the 2015 call for applications.

Call for grants applications for infrastructure of national interest 2015

- In 2015, university consortia can apply for grants, for an eight-year period, for national infrastructures needing to renew an ongoing contribution from the Swedish Research Council.
- A targeted call is also planned in 2015 for two-year grants relating to operation and coordination of databases within Social Sciences and Medicine.
- Applications for Swedish participation in international infrastructure in 2015 are made according to the same principles as in previous years.

Need for structural measures 2015–2020

New management for research structure of national interest

A new model of prioritisation and financing of national research infrastructure will be implemented gradually over the period 2015–2020. This model is described in a separate section. Over the next few years, the Swedish Research Council will also need to look over the Swedish participation in international research infrastructure, to ensure that it leads to the greatest possible benefit from a national perspective. A coherent prioritisation of national and international commitments is the aim.

Balancing research and research infrastructure

Research needs should guide what investments are made in infrastructure, and the effect of such investments depends on the development within the research areas using the infrastructure. The construction as well as the use of research infrastructure requires the involvement of people with cutting-edge expertise. This means that large investments in infrastructure should also be associated with equivalent investments in research. RFI therefore proposes that the Government appropriates new funds for research and education within areas where large national and international infrastructure investments have been made.

Information and training

The infrastructures need to assist researchers with more information and training on how they can utilise resources. Researchers must have the necessary knowledge of methods and technologies applied to the different infrastructures, and be offered help in planning research questions and experiments. User support and training measures are decisive factors in the impact of the infrastructures. Swedish higher education institutions and infrastructure should pay more attention to this function.

Professional development and career paths for infrastructure staff

It is important to encourage Swedish and international researchers to get involved in the construction of infrastructure and to offer their expertise. To facilitate this process, such work should be formally recognised. The discussion regarding the researchers' qualifications should be coordinated, both at the Swedish higher education institutions and among funding bodies, for example within the scientific councils and committees of the Swedish Research Council.

Instrument and technology development, and industry involvement

Participating in infrastructure projects affords Swedish researchers and industry opportunities to be involved in the development of instruments and technology, in the actual construction of instruments as well as the development of analysis tools and supporting software. Swedish technology is at the cutting edge, and this type of participation needs to be encouraged and supported to a much higher degree. Wide support and collaboration

from all relevant stakeholders is needed when it comes to the activities of Vinnova's newly established Industrial Liaison Office function, ILO.

Need for coordination and development 2015–2020

The new investments brought up in this report relate primarily to increased coordination and accessibility of existing resources.

Supporting e-infrastructure

From the international and national perspectives alike, the importance of e-infrastructure in research is growing within several subject areas. The report *Science cases for e-infrastructures*[1] describes how the quality of both basic and specialist Swedish research can be increased if the digital tools are developed and adapted to the needs of the research infrastructure. The basic funding for large-scale computer resources for calculation and storage needs to be increased, as does the capacity of networks for digital communication. Major investments in advanced user support and training must permeate the entire research system, and include general qualification improvements and increased access to e-expertise at the higher education institutions. National stakeholders, like the Swedish Research Council and the Swedish higher education institutions, need to work together to develop new funding models for e-infrastructure for the Swedish research system, in order to meet the growing needs.

International investments

At many international infrastructure facilities, major investments or upgrades will be implemented within the next few years, and new international infrastructures relevant to Swedish research are being planned. The Swedish Research Council needs to develop a cohesive national process for the prioritisation of new commitments.

1 Science cases for e-infrastructures, A. Ynnerman, Vetenskapsrådet 2014, ISBN: 978-91-7307-240-3

Coordination of national investments within specific areas

Within several areas, there is currently a fragmented infrastructure landscape, which must be coordinated and consolidated. The following is a description of the most pressing coordination needs. The background for these will be developed in the area-specific sections.

Databases for social sciences and medicine In 2013, the Swedish Research Council conducted an investigation of the need for national coordination of survey investigations, longitudinal studies and cohort studies[2]. The investigation points to a need for a nationally coordinated system for quality-assured, research-based individual databases within social sciences and medicine. This work is related to the Swedish Research Council's Government commission of building an improved national infrastructure for register research. It also relates to the need for clearer information and documentation of existing data sources, and the establishment of quality-assured systems for coordination, archiving and recycling of data within the framework of current legislation.

National structure for biobanks, databases and medical registers. Life science research depends on access to information on biological materials and related individual data, for which the sources of information are often found within the health services. RFI intends to provide continued support for the efforts to create a common national biobank infrastructure for both research and health services.

Bioinformatics and systems biology. The Government has made great strategic investments in the construction of the Science for Life Laboratory (SciLifeLab) as a national infrastructure for large-scale molecular biology research within the life sciences. The formation of these experimental platforms places great demands on effective management, storage and analysis of large amounts of biological data. Together with the Knut and Alice Wallenberg Foundation (KAW), the Swedish Research Council is working to promote a coordinated, common national infrastructure for bioinformatics and systems biology, which will be seen already in the Swedish Research Council's call for applications in 2015. The Swedish Research Council and KAW have also agreed to strive towards a joint computer infrastructure for the secure handling of sensitive personal data within the framework of SNIC.

2 Nationell samordning av frågeundersökningar och längdsnittsstudier, R. Eriksson, Vetenskapsrådet 2014, ISBN: 978-91-7307-235-9

Biological imaging and structure determination The Swedish Research Council supports a number of nodes at Swedish higher education institutions, which provide equipment for biological and medical imaging. The national network Swedish Bioimaging aims to be a joint organisation for these nodes. In 2012, two investigations were carried out in respect of equipment within the areas of biological mass spectrometry and microscopy in the field of life sciences[3][4]. These investigations highlighted a need to make advanced and expensive cutting-edge equipment accessible, and the Swedish Research Council therefore advertised targeted grants in 2014, with the intention of coordinating the accessibility of such equipment.

Collaboration between infrastructures for ecosystem analysis Ecological research, such as the study of terrestrial, limnic and marine ecosystems, ecosystem services and research within biodiversity, are traditionally strong areas in Sweden. The Swedish Research Council supports a number of distributed infrastructures in the area. They handle e-infrastructure, which collects and makes data available, as well as metadata and field infrastructures, which deliver long time series of field observations. In order to achieve a clear infrastructure landscape and an effective use of research resources, these investments should continue to be developed and coordinated.

Collaboration between infrastructures for solid earth analysis Solid earth research relates to evolution and climate, but also to questions regarding final disposal of nuclear fuel and the mining of minerals and oil. The Swedish Research Council supports a number of infrastructures within this area, such as scientific drilling, collection of data and analysis for the study of earth sciences and mineral resources, and of geodesy. In order to achieve a clear infrastructure landscape and an effective use of research resources, these investments should continue to be developed and coordinated.

3 Nationell samordning av biologisk masspektrometri, G. Hansson, Vetenskapsrådet, 2014, ISBN: 978-91-7307-229-8

4 Möjligheter till samordning av mikroskopi inom livsvetenskaperna, K-E Magnusson, Vetenskapsrådet, 2014, ISBN: 978-91-7307-241-0

Development of facilities hosted by Sweden

Utilise the opportunities presented by the MAX IV Synchrotron Light Facility and the European Spallation Source (ESS). The construction of the research facilities MAX IV and ESS opens up new research opportunities within a wide spectrum of areas using X-ray technology and neutron scattering. There is an urgent need to take a comprehensive approach, with targeted calls for grants for research, doctoral programmes and industry collaboration, so that the Swedish research which can make use of these facilities is broadened and deepened. Swedish participation in existing infrastructures within this field abroad, and the development of nodes at higher education institutions other than Lund University ought to reinforce the Swedish hosting of MAX IV and ESS. With support by the Swedish government, the MAX IV Laboratory and Swedish universities, along with the Swedish Research Council, KAW and other funding bodies, need to promote the participation of other countries in the continued construction and operation of experimental stations at MAX IV.

Ensure implementation of the radar facility EISCAT-3D The international organisation EISCAT, which is based in Kiruna, is planning an upgrade of its radar facility for ionosphere studies, through an initiative called EISCAT-3D. Negotiations between the participating countries are underway for the construction of the first phase to begin within the next few years. The plan is for Sweden, Norway and Finland to jointly host the facility, which has transmission and reception stations in all three countries. National support and funding is needed to ensure that Sweden is able to host EISCAT-3D and contribute to the construction of its first phase.

Analysis and investigations

The Swedish Research Council has identified a need for national coordination of infrastructures within engineering sciences, humanities, high-resolution microscopy for material analysis, marine research and animal testing. Analysis and investigations of these areas is therefore recommended.

Need for new investments 2015–2020

A limited number of known and pressing new investments for the Swedish Research Council during the period 2015–2020 are listed in Table 1. These investments are motivated by investigations commissioned by the Swedish Research Council during the period 2012–2014. Further needs for new investment are expected in conjunction with the 2016 revision of the Swedish Research Council's Guide to Infrastructures.

Table 1. Known new needs for the construction of infrastructure of national interest 2015–2020 (the Swedish Research Council's share of the cost)

Infrastructure	Period	Estimated cost
Upgrading international facilities	2018–2020	Assessment pending
E-infrastructure	2015–2020	SEK 850 million*
Biological microscopy and mass spectrometry	2016–2020	SEK 150 million**
Databases within social sciences and medicine	2016–2020	SEK 150 million***
The radar facility EISCAT-3D	2015–2020	SEK 120 million***

* This is the estimated increase in Swedish Research Council grants to supporting e-infrastructure during the period 2015–2020. The needs are described in the report *"Uppdrag till SNIC avseende kartläggning av andra infrastrukturers behov av storskaliga datorresurser för beräkning och lagring"* (Assignment to SNIC pertaining to the investigation of other infrastructures' needs for large-scale computer resources for computation and storage)[5] and in the investigation into researcher needs for supporting e-infrastructure[6]. The estimation does not consider the needs of SUNET.

** Needs based on the reports *Nationell samordning av biologisk masspektrometri*[7] (National coordination of biological mass spectrometry) and *Möjligheter till samordning av mikroskopi inom livsvetenskaperna*[8] (Possible coordination of microscopy within the life sciences). A targeted call was issued in 2014, and the new coordinated infrastructure is expected to be launched in 2016.

*** A targeted call relating to databases within social sciences and medicine is planned for 2015, based on the report *Nationell samordning av frågeundersökningar och längdsnittsstudier*[9].

**** Minutes from the RFI meeting of 17–18 September 2014. Ref. no. 821-2013-1730 and 822-2013-1735.

5 Uppdrag till SNIC avseende kartläggning av andra infrastrukturers behov av storskaliga datorresurser för beräkning och lagring, Swedish Research Council, ref. no. 823-2014-7381

6 Science cases for e-infrastructures, A. Ynnerman, Vetenskapsrådet 2014, ISBN: 978-91-7307-240-3

7 Nationell samordning av biologisk masspektrometri, G. Hansson, Vetenskapsrådet, 2014, ISBN: 978-91-7307-229-8

8 Möjligheter till samordning av mikroskopi inom livsvetenskaperna, K-E Magnusson, Vetenskapsrådet, 2014, ISBN: 978-91-7307-241-0

9 Nationell samordning av frågeundersökningar och längdsnittsstudier, R. Eriksson, Vetenskapsrådet 2014, ISBN: 978-91-7307-235-9

GOALS AND DEFINITION OF RESEARCH INFRASTRUCTURES

Goals for research infrastructures

Conditions for pioneering research

The Swedish Research Council is responsible for ensuring that Swedish research has access to the national and international infrastructure needed to excel within basic research and the sectoral research relating to the state-owned research-funding bodies Forte, Formas and Vinnova. Funding for research infrastructure owned, for example, by the Swedish National Space Board and the Swedish Energy Agency, is not currently channelled via the Swedish Research Council. Large-scale and long-term research infrastructures constitute strategic investments that shape the Swedish research landscape.

Benefit to society

Infrastructure investments are expected to impact on social developments, for example through knowledge creation within different social sectors, technological development and innovations, and through conditions to come up with common solutions to global social issues. A few examples where access to infrastructure has been vital to basic research with a great social impact include Argo (3,000 buoys in the ocean, which proved that heat and carbon dioxide are absorbed by the sea), EISCAT (international radar facility for ionosphere studies, which is also used to map space debris), CERN (initiated and developed the web) and SHARE (mapping of economic and social consequences of ageing in different parts of Europe, which among other things has been used to reform pension systems in various countries).

Definitions and criteria

The Swedish Research Council applies the following definition of the term 'research infrastructures':

- Research infrastructures constitute necessary tools for conducting research of the highest quality.
- Research infrastructures include facilities, instruments, knowledge bases and services, and are intended for use by researchers or research groups within basic or applied research within all research areas.
- Research infrastructures can be centralised, distributed or virtual, and the infrastructure is made available based on academic assessment criteria.

Research infrastructures may have different characteristics within different areas. They can, for example, be large research facilities for studies within materials science or physics, or distributed databases for research within the humanities, social sciences or medicine. The general rule for all infrastructures receiving support from the Swedish Research Council is that they must be generally accessible to Swedish researchers, and that access is regulated based on academic excellence. They may be national or international, but since 2008, they must be of national interest and fulfil the following general criteria, in full or in part. They must:

- provide the conditions for world class research
- be of a broad national interest
- be used by several research teams or users with highly advanced research projects
- be so extensive that individual teams cannot run them on their own
- have a long term plan for scientific goals, funding and utilisation
- be open and easily accessible to researchers, industry and other stakeholders
- have a plan for accessibility (in terms of using the infrastructure, access to collected data and presentation of results)
- in relevant cases, introduce new cutting-edge technology.

A NEW MODEL FOR THE PRIORITISATION AND FUNDING OF NATIONAL RESEARCH INFRASTRUCTURES

The Swedish Research Council is currently funding several national infrastructures, which have been granted funding based on annual rounds of applications. These are mentioned in appendix 1, and described more closely under each respective area. In 2014, the Board of the Swedish Research Council has initiated a review of the processes involved in the prioritisation, financing and organisation of national research infrastructures. The basis of this work is an investigation conducted as a subproject within the Swedish Research Council's work on strategic operations management[10].

Important starting points have been that the new model should facilitate a more clear prioritisation process, and that it is to encourage greater longevity and participation in decisions, responsibilities and co-financing by the higher education institutions. It is difficult to find a format that is suitable to all research infrastructures. The new model will therefore be implemented gradually, and will initially require a flexible management. At the same time, mechanisms that link infrastructure investments to research investments are also required.

Prioritisation

The new model is based on cyclically recurring periods for the development of the Swedish Research Council's Guide to Infrastructures ("the guide"), and on calls for applications. The guide is proposed to set the tone for calls for applications in the following years. This means that the possibility to apply for the Swedish Research Council's infrastructure grants for coordination, development, construction and operation of national and international infrastructure depends on the infrastructure project being identified and prioritised in the guide. One principle that continues to be important is that applications concerning both new and existing infrastructure are to be assessed in a quality-assured process. The model thereby entails the end of

10 Synpunkter på planering, organisation, styrning och finansiering av svensk nationell infrastruktur, K. Bremer, Vetenskapsrådet 2013, ISBN 978-91-7307-227-4

the Swedish Research Council's annual open call for applications relating to infrastructure grants (planning, equipment and operational grants).

The basis for the guide is to be arrived at through a wide needs inventory. Different stakeholders, such as universities and other organisations conducting research as research-funding bodies, are invited to submit proposals for the initiation of new research infrastructures based on research needs. Research groups from several higher education institutions also have the possibility of expressing needs for infrastructure together. Based on the collected data from the needs inventory, the Swedish Research Council will then make an academic and strategic prioritisation of the identified needs. This prioritisation constitutes the foundation for the presentation in the guide, and must take place after consultation with higher education institutions in Sweden, which are potential host organisations, and with the Scientific Councils of the Swedish Research Council.

The guide is to be published once every four years, and a smaller update is planned every other year. Applications for national infrastructure must generally be made jointly by more than one university (or other organisation). This procedure ensures the national interest and the financial stability of the infrastructure.

The application must also include a financing plan and a binding commitment to financially support construction and operation from each of the partners involved. The grant from the Swedish Research Council will be paid out once a complete consortium agreement and specific terms and conditions for the contribution have been signed.

Great focus will be placed on maturity and implementation when assessing applications for the construction of new national infrastructure. The application must contain a detailed scientific, organisational and technical plan, along with a plan for supporting e-infrastructure. Great emphasis will also be placed on having a realistic and sustainable financial plan. A decision to fund in principal involves the Swedish Research Council entering into negotiations with the responsible consortium. This may also involve negotiations on hosting the infrastructure project.

Organisation and evaluation

Research infrastructures require coordination and collaboration. In order for research infrastructures to function independently of the interests of individual researchers or research undertakings, the organisation and management need to be as neutral as possible, and international peer review is required during follow-up. Each infrastructure will be led by a board with

overall responsibility for the activities. These boards are to be composed of highly merited national and international researchers and experts on research infrastructures, who are not part of a university management or hold other equivalent management positions within the academic sector. The Swedish Research Council will continuously monitor the activities and evaluate them prior to making any decisions on renewed funding.

Funding

The proposed upper limit for Swedish Research Council funding for national infrastructure is eight years. If the infrastructure remains a priority in the Swedish Research Council's Guide to Infrastructures, it can apply for funding for another period. As a guideline, the Swedish Research Council will strive towards an even distribution of the infrastructure's total costs between the consortium and the Council, calculated over the whole grant period. After a decision regarding a grant, the Swedish Research Council and the responsible consortium enter into negotiations. For really large national facilities, such as MAX IV, Onsala Space Observatory and SNIC, special negotiations are required regarding the level of support from the Swedish Research Council.

SWEDISH INFRASTRUCTURE INVESTMENTS FROM AN INTERNATIONAL PERSPECTIVE

The Swedish Research Council participates as a member of several international infrastructures. For Sweden, membership in international infrastructure investments entails great benefits, as it gives access to advanced equipment and facilities that are too expensive or too large to be constructed and operated nationally. At the same time, each individual membership is a financial commitment that ties up funds for many years to come, thus influencing future room for manoeuvre. Future prioritisations and financing of Swedish participation in international infrastructure need to be placed in relation to national investments and needs, as well as to the international processes guiding the development in Europe and globally.

The European landscape: Horizon 2020, ESFRI and Science Europe

In 2014, the EU launched its new research programme for the period 2014–2020, Horizon 2020, in which the support for research infrastructures was markedly increased compared to previous programmes. The construction of pan-European research infrastructures has been facilitated by the fact that in 2009, the EU established a new organisation format for joint European projects called the European Research Infrastructure Consortium (ERIC).

ESFRI (European Strategy Forum on Research Infrastructures) is a key organ for the surveying and prioritisation of pan-European infrastructures, consisting of representatives from the EU member states and others. Since 2002, ESFRI have identified important European infrastructures, which are presented in *The European Roadmap for Research Infrastructure*.

Science Europe was formed in 2011 as a research policy organisation, whose purpose it is to reinforce the collaboration between research organisations in Europe. In consultation with ESFRI, Science Europe has worked out the principles for access to pan-European infrastructure.

Sweden has actively participated in the European infrastructure collabora-

tion, and should continue to prioritise strategic representation in European forums where infrastructure matters are discussed and decided.

International infrastructure hosted by Sweden

The benefits of Sweden hosting internationally leading infrastructure are scientific as well as strategic and social. The research-intensive environments around these infrastructures attract researchers and companies, and lead to regional investments, which is already happening in conjunction with the construction of MAX IV and ESS in Lund. At the same time, hosting means that Sweden has to take on a great responsibility for implementation, use and financing strategies at all levels.

ESS and MAX IV

The European Spallation Source (ESS) is a research facility for detailed analysis of materials and other molecular structures, which will be used within a wide spectrum of areas. The facility was identified at an early stage by ESFRI as an important European infrastructure, and it is now being constructed in Lund with at least 17 participating countries. Sweden and Denmark are responsible for coordinating the construction and operation of the facility, which is planned to be ready for use in 2019.

The development and construction of the nearby MAX IV Synchrotron Light Facility is a result of Swedish researchers' determination and recognised expertise within the field of accelerator physics and use of synchrotron light. The construction of the accelerator and the first phase of beamline development for MAX IV have mainly been a Swedish infrastructure project, supported only by the closest neighbouring countries. For the construction and operation of beamlines in later phases, an expanded international collaboration is required to ensure that the exceptional conditions of the facility are utilised optimally. Academic and political support in negotiations is a condition.

Expanding EISCAT to EISCAT 3D

Sweden hosts the international organisation EISCAT Scientific Association, which is based in Kiruna. The facility is intended for research within space, plasma and atmospheric physics, and is also used for research within meteorite astronomy, space safety and radio astronomy. The existing EISCAT radar

system in northern Scandinavia and Finland will be phased out within a few years, when the frequency rights are taken over by commercial actors. As its replacement, the ESFRI project EISCAT 3D is at the threshold between the planning and implementation phases. In this stage, the Swedish Research Council supports planning and international coordination. At least five countries in the EISCAT Council, including Sweden, are expected to make a decision in 2015 or 2016 on funding for the construction of EISCAT 3D.

Swedish participation in distributed international infrastructures

The distributed infrastructures in which Sweden is currently a member are listed in the table of appendix 1 and described more closely under each respective area. What is characteristic for the distributed international infrastructures is the relatively low cost of membership in the coordinated international central unit, and the relatively larger cost of construction, and above all the operations of the national parts of the infrastructure, which often function as nodes in the international infrastructure.

After a decision from the Swedish Riksdag and Government, the Swedish Research Council has been commissioned to prioritise and, within certain economic parameters, negotiate the conditions of Swedish participation in a number of the European infrastructures on the ESFRI Roadmap 2010. The Swedish Research Council's prioritisation of participation is based on an application submitted by a potential Swedish node to the European infrastructure. This assessment takes into consideration the scientific level of the infrastructure, its technical and organisational plans as well as its strategic importance for Swedish research.

Swedish participation in international infrastructure facilities

The distributed infrastructures in which Sweden is currently a member are listed in the table of appendix 1 and described more closely under each respective area in the field overview. In common for many of the international facilities is the fact that they constitute very long-term commitments, with significant costs. This mainly applies during the construction phase, but

also later on in the operational phase, and then particularly when upgrading the facility.

Many of the international infrastructures are controlled by intergovernmental conventions, which are particularly stable organisations with lengthy and complicated processes for possible withdrawal. Swedish participation in convention-related collaboration at the international level should therefore be preceded by a careful investigation and consideration of the scientific use.

Swedish researchers are also often involved in the development, construction, operation and upgrade of specific experiments at international facilities. This work is organised in some form by the research consortium, and apart from the grant for the actual facility, it is generally funded by the member countries. Through the research consortiums, the participating countries jointly develop specialised, often expensive instruments and laboratories at the facility adapted to the experiments, which often constitute research infrastructures as such. During an assessment of Swedish participation in international facilities, it is therefore important, as early as possible in the process, to consider which Swedish research consortiums could be interested in participating, and what costs would be entailed in such participation.

Parts of the Swedish funding for the construction of new facilities may be in the form of in-kind contributions. This means that part of the member fee is paid through Swedish researchers contributing to the facility with equipment and/or expertise, which is beneficial to Swedish knowledge and Swedish technological development. In-kind contributions have been a significant part of the Swedish contribution to the international facilities XFEL and FAIR, which will both shift from construction phase to operational phase in the next few years. At CERN, ESO and IceCube, significant developments and upgrades are being planned.

Swedish researchers are already participating in development work within infrastructures in which Sweden is not yet a member. Some of these infrastructures are particularly interesting, for example the radio astronomy facility SKA, the high-energy astrophysics facility CTA, and the research reactor MYRRHA.

Examples of other major Swedish investments

Biobanks, databases and register research

Sweden has a unique potential within medical, public health science and social science research to use national biobanks, databases and registers based on personal identity numbers. The national registers are based on a century-long tradition of careful data collection on the composition and living conditions of the Swedish population. The national biobanks and modern molecular technology, combined with researcher-initiated cross-sectional studies, longitudinal studies and cohort studies provide brand new opportunities to study underlying mechanisms, early discovery and treatment of diseases. In addition, Sweden has a number of general systems for health services and social insurance, as well as national quality registers on the country's endemic diseases. There are also a few major national investments relating to the development and study of animal models, in order to better understand the progress of various diseases.

Swedish registers and biobanks have primarily been established for a purpose other than research, such as national statistics and health services. The lack of integrated systems between various register-keeping authorities, the need for human research to go through ethics reviews and the importance of guaranteeing personal integrity have made the use of national biobanks and registers for research purposes taxing. Continued efforts to facilitate effective use of these research resources are needed.

Molecular biosciences (Science for Life Laboratory)

Sweden has broad knowledge and a strong tradition when it comes to molecular bioscience technologies, medical research, environmental research and drug development. To maintain this position in an increasing global competition, significant investments have been made in terms of infrastructure and research at the national level. A large government investment in the construction of the Science for Life Laboratory (SciLifeLab) was made with the intention to create national technology platforms and infrastructures for molecular biology, and to conduct world-class research. Several of these infrastructures also receive funding from the Swedish Research Council, and it is becoming increasingly important for them to be linked to other infrastructure activities, such as national registers and biobanks.

TOMORROW'S CHALLENGES

The task of the Swedish Research Council to support and develop research infrastructures within all subject areas requires dealing with many complex issues, and collaboration between many different stakeholders. The costs of infrastructure of national interest are generally increasing, and the raised ambitions of Sweden follow the trend in the Nordic countries, Europe and the rest of the world.

Balancing research and research infrastructure

The Swedish Research Council's funding of research infrastructures is to support research of the highest scientific quality. This requires research and infrastructure investments to be coordinated, which is being emphasised to an increasing degree. The responsibility for the infrastructures is being shifted towards the higher education institutions, which in their prioritisations of local, national and international infrastructures need to relate to the high-quality research they are conducting. The Scientific Councils and committees of the Swedish Research Council are playing an increasingly important role in the prioritisation of infrastructure projects.

Not least the construction of MAX IV and ESS have contributed to the changed landscape. It would be reasonable for these major infrastructure investments to be accompanied by targeted reinforcements to research that could contribute to the design of the facilities and optimise their use. The challenge lies in traditional research, which currently uses synchrotron light and neutron scattering, as well as new researchers within new research areas. These research groups need training and opportunities to test hypotheses and methods at facilities abroad, and when appropriate, through the universities investing in local centres and laboratories, and in smaller instruments and infrastructures.

Information and training

The accessibility of the infrastructures needs to be highlighted on a broad front so that researchers within all areas are aware of what infrastructure is available, and what use it could have in their own research. Researchers

from Swedish higher education institutions and international researchers alike shall be able to utilise the resources. Knowledge of methods and technologies at the different infrastructures is necessary to ensure effective use. Infrastructures should therefore dedicate significant effort to professional development and user services, such as planning of research questions and experiments and principles of analysing data. User support and training measures are decisive factors in the impact of the infrastructures. For the infrastructures supported by the Swedish Research Council, stricter demands will be made on the implementation and follow-up of information measures, service and training.

Professional development and career paths for infrastructure staff

Research commitments in joint national and international infrastructure are important for the research community at large. One structural issue is that the researchers who devote longer periods of time to various aspects of constructing or operating research infrastructures risk falling behind in their academic careers. Experts at the infrastructures need to be given an academic identity at the universities, along with opportunities to develop and gain qualifications. The professional structure and career paths of the whole research system need to be adjusted to these needs.

Instrument and technology development as well as industry and researcher involvement

The countries participating in the development of large facilities can usually benefit from this by winning procurements of materials and components. Sweden rarely achieves a reasonable industry return in relationship to its member contribution to the infrastructure. Sweden thus loses the knowledge transfer that the industrial contracts could contribute to. In 2014, Vinnova has been tasked with promoting collaboration between the research and business sectors on Swedish and international research infrastructures, with the aim of increasing the participation of Swedish companies in the construction and use of research infrastructure facilities. This work is now underway, for example through the establishment of an Industrial Liaison

Office (ILO) function.

Positions for staff at international infrastructures are generally advertised in the member countries. In this case too, Sweden often has a disproportionately low level of positions in relation to the member fee. This is a fact that needs to be noted, and measures need to be taken where possible.

Instrument and technology development conducted by researchers at Swedish higher education institutions has previously been successful. This activity is in the borderland between research and infrastructure development, and is of decisive importance to Swedish skills development. Clear incentives for funding and qualifications from this type of activity are required.

Need for supporting e-infrastructure

Infrastructures whose goal it is to supply e-Science methods and technologies are often referred to as e-infrastructures, which includes everything from computers, databases and networks to software and user support. Simulations, visualisation and data-based research, popularly referred to as Big Data, is rapidly becoming a given part of an increasing number of research areas, which means that research conditions are fundamentally changing.

Major contributory factors to the explosive increase in research data are the technological developments and the construction of infrastructures that generate significant amounts of data for each experiment. Research conducted at such infrastructures depends on well-functioning e-infrastructures.

A critical factor within data and calculation-rich research areas is the limited access to e-Science experts with the capability of contributing advanced user support to other researchers. This needs to be highlighted when granting support for both research and infrastructures. Greater expertise is required in parallel with major investments in hardware for capacity and capability calculations, storage possibilities and accessibility of large-scale, complex data, development of software and analysis tools as well as fast communication tools. The researchers' need for supporting e-infrastructure is described in more detail under each respective field description, and in the Swedish Research Council report *Science cases for e-infrastructures*[11].

If the current trend continues, financing of e-infrastructures will become an important issue within multiple subject areas. Today, e-infrastructure resources are often perceived by the users as being free of charge, but if the expansion is to continue, it will be necessary to consider new financing

11 Science cases for e-infrastructures, A. Ynnerman, Vetenskapsrådet 2014, ISBN: 978-91-7307-240-3

models for e-infrastructure. The following three aspects need to be taken into account:

1. Research projects with a great need for supporting e-infrastructure need to be identified, and specific resources need to be set aside within each project.

2. All research infrastructures need to include supporting e-infrastructure in the budget. The realism of the plan will be part of the assessment of the infrastructure's maturity.

3. Previous investments in experimental infrastructures need to be supplemented with follow-up funding of computer resources for large-scale computation and storage, and of digital communication networks. These needs are very extensive.

Processing personal data in research

To safeguard personal integrity, there are specific legal and ethical regulations when it comes to the use of personal data for research purposes. The support and trust of research in society depends on maintaining the protection for the integrity of private individuals. Researchers therefore need to adhere to both national legislation and international law.

The basic rule is that research may only be conducted if the individual has expressly consented to participating. Such consent can only be given once information has been obtained about the research, and it must be voluntary, expressed and defined for specific research. There are exceptions from the rule of consent.

In order to effectively combine existing data stored with various stakeholders, and to reuse data that has been collected in previous projects, it is desirable to create cohesive and compatible research databases, which would create longevity, continuity and cost-effectiveness in the data processing. The legal conditions for this have been described in great detail in the Swedish Research Council report *Rättsliga förutsättningar för en databasinfrastruktur för forskning*[12] (Legal conditions for a research database infrastructure). The legislation may be considered difficult to survey and contradictory in parts.

The official report *Unik kunskap genom registerforskning*[13] (Unique know-

12 Rättsliga förutsättningar för en databasinfrastruktur för forskning, Vetenskapsrådet 2010, ISBN: 978-91-7307-179-6

13 Unik kunskap genom registerforskning, SOU 2014:45

ledge through register-based research) presents assessments and proposals on ethics reviews, passkey procedures and secrecy regulations. The official report also proposes the introduction of a special law, which is generally applicable to research databases.

In its 2013 appropriation directions, the Swedish Research Council was assigned to develop activities within the agency that will improve the accessibility and facilitate the use of register data for research purposes (2012/13:30). The commission also involves assisting researchers with information on registers and relevant legislation. A Register Data Board consisting of representatives from the major data owners and national research interests has been established to ensure that principally important decisions made within the framework of the Swedish Research Council commission are supported by the concerned authorities and organisations. Within its commission, the Swedish Research Council will establish an internal coordination function, and continue to develop the information portal www.registerforskning.se.

Coordination of infrastructure for improved overview and use

To make it easier for researchers using multiple tools, the need for coordination between infrastructures is great. This primarily relates to social sciences, environmental science and life sciences. Within these disciplines, it is essentially a matter of coordinating data, terminology and standards and of establishing interdisciplinary and compatible data systems.

The 2015 call for applications is expected to result in coordination within several areas:

- databases within social sciences and medicine, biobanks and registers
- bioinformatics and systems biology
- biological imaging and structure determination
- infrastructure for ecosystem analysis and infrastructure for solid earth analysis, respectively.

New coordination requirements are expressed through needs for investigations within engineering sciences, context databases, and databases within the humanities, high-resolution microscopy for material analysis, marine research and animal testing. These areas are described in the field

overviews, and investigations are expected to lead to prioritisations and calls in 2017 or 2019.

As regards to the implementation of the infrastructures on the ESFRI Roadmap 2010, the need for coordination has been noted and led to an infrastructure call within Horizon 2020 for the coordination of ESFRI infrastructure clusters.

Towards a clearer future infrastructure landscape

In order to face the challenges of tomorrow, and meet the needs of Swedish researchers for necessary research tools, a transparent prioritisation process is required, along with preparedness for long-term solutions that also allows for dynamics and renewal. The ambition is to counteract fragmentation by forming coordinating infrastructures within broad disciplines. The entire research system needs to be involved in the complicated processes that are to yield good decisions. The new model for prioritisation and funding of research infrastructures has a clearer infrastructure landscape as the goal. The balancing of local, national and international infrastructures requires well-informed discussions within the research community to identify the most urgent investments at each level. Involvement in international research infrastructure is of particular value, as it enables international academic exchanges and a broad knowledge transfer. A good interaction between various stakeholders and levels needs to be developed, particularly as the type of advanced and long-term investments that research infrastructures constitute require both strategic political decisions and highly qualified academic expertise. In light of this, the Swedish Research Council is working to support, bring together and coordinate the stakeholders and resources that in various ways have proven to be key factors in the creation of a beneficial Swedish research landscape.

MATERIALS SCIENCE

Description of the field

Most things in our everyday lives are governed by material properties. The properties of a material would be, for example, its hardness, workability, conductivity, magnetism, transparency or corrosion resistance. The properties decide the quality of everything from the construction materials included in houses, bridges and airplanes to the functional materials at the foundation of microelectronics, drugs, batteries and fuel cells. Even life itself, with its cells and molecules, is an advanced form of material. Materials science can therefore be seen as a collective name for several different disciplines within physics, chemistry, geology, biology and medicine, where researchers often collaborate across traditional academic lines.

Modern materials research is largely challenge-driven. Increasing the understanding of materials from the atomic level and up, in order to develop materials with new and unique properties, is of the utmost importance. New possibilities of designing nanomaterials will be vital to areas such as energy, environment and medicine/health. These three areas are also very important from a global perspective, and are thus at the top of the list for prioritised areas within the EU research and innovation programme Horizon 2020. Innovations within the field of materials are also of great importance when it comes to the sustainable development of society and the continued competitiveness of the industry, both nationally and internationally.

The development of new material is necessary to produce, transport, store and transform energy in future sustainable energy systems, such as batteries and fuel cells. In the same way, it is important for social development with new materials that may trap substances that are harmful to the environment, the use of renewable raw materials, the recycling of materials, the development of light-weight and composite materials to save energy during transport, and in applications within information and communication technology. It is also important to develop materials which can take up environmentally hazardous substances. Multifunctional materials, which combine several properties such as magnetic, catalytic and electrical ones, is an area of research in which Sweden excels. These types of materials are used in detectors and sensors, among other things.

Sweden holds a strong position within materials research, and an important

contribution to the country's export revenues is products based on material innovations. Prominent areas for Sweden include research within steel and metal, semiconductors, fibre and polymer materials, biomaterials and biocompatible materials, nanomaterials, including graphene, energy-related materials, including batteries and green catalysts. Building a material from its smallest elements, i.e. material synthesis, places great demands on the surrounding environment, and access to a cleanroom infrastructure thus plays an important part. An emerging trend within material research is additive manufacturing, which includes 3D printers that can build new structures on a micrometre scale. This paves the way for new properties and allows for the quick development of prototypes.

Material research is a largely experimental discipline. The great demand for advanced infrastructure for materials research created a culture of coordination and sharing at an early stage, which has led to prominent research environments when it comes to synchrotron light and neutron scattering facilities, as well as cleanroom laboratories. It should be noted that researchers within materials often use a number of different infrastructures, since the combination provides them with more comprehensive information. One example is the complementarity of X-ray light and neutrons, which results in different contrasts depending on the type of atoms, and therefore different "pictures" of a material.

However, the development of modern computers, new theoretical methods and calculation algorithms means that virtual design of material and simulations are now an equally important part of the research on and development of new materials. This field is therefore in need of both experimental infrastructures and e-infrastructures. Advanced characterisation methods are essential to understanding the properties of a material. They consist of both large infrastructure facilities (neutron sources, synchrotrons, cleanrooms) and local infrastructures used daily in the proximity of the researchers. On the theoretical side, there is a great need for computation resources in the form of both national and international supercomputer centres. There is also a need for e-infrastructure in terms of processing the large amounts of data produced by experiments at the synchrotron, neutron and free-electron laser facilities.

Infrastructure financed by the Swedish Research Council

ESRF

Sweden is a member of ESRF (European Synchrotron Radiation Facility) via NORDSYNC, a Nordic union initiated by NordForsk. ESRF is the largest synchrotron light facility in Europe, located in Grenoble, France, with 20 European countries as its members. The ESRF ring is run at an energy of 6.0 GeV, making the hard X-ray range its area of strength. There are currently 43 beamlines available for use, and another few are being rebuilt as part of an extensive upgrade. Most synchrotron light-based methods are available at ESRF. Swedish researchers primarily use ESRF within structural biology, for determination of material structure, and particularly that of solid materials under high pressure and/or high temperatures; speciation of metals in biosystems, water and land with the help of X-ray spectroscopy; determination of reaction dynamics in primarily catalytic systems; determination of electron structures and magnetic properties in solid materials; structure determination of soft materials; and for three-dimensional imaging, for example of fossil animals and plants (tomography) and scanning transmission X-ray microscopy (STXM)

The ESRF is currently undergoing an upgrade programme to further improve the performance of the facility. The first of two parts has just been completed, and the second is to be carried out in 2015–2019. The second upgrade will provide ESRF with properties comparable to those that the great ring of MAX IV will have, with a significantly increased brilliance and coherence in the X-rays.

ESS

The ESS (European Spallation Source) is a joint European initiative to build a neutron scattering facility in Lund. The ESS will be more powerful than all existing and planned facilities in terms of intensity and detection of scattered neutrons. This is an important step in the development of neutron scattering. The method is currently limited by the neutron flux, which means that large samples and/or long measuring periods are required. Future accessibility of neutron scattering instruments is furthermore predicted to be limited, since many of the current resources are old and reactor-based, and may come to be closed for not entirely scientific reasons.

ESS is planned to deliver 5 MW (the proton accelerator) with 22 planned

instruments. This will improve research on large-scale structures and slow dynamics, such as soft matter, biosystems and magnetic materials. Construction of the facility began in September 2014, and the first neutrons are expected in 2019. During the period up until 2026, a first operational phase will be carried out, while construction is still underway.

ILL

ILL (Institute Laue Langevin) is a leading neutron scattering laboratory. The laboratory is located in Grenoble, France, and has some forty different instruments. The instrumentation spans all types of neutron scattering techniques and the users come from many different research disciplines, from physics and biology to archaeology (cultural heritage investigations).

ILL is an international facility with three owners (France, United Kingdom and Germany) and thirteen Scientific Member countries. Sweden is a member, along with Denmark and Belgium, through the TRANSNI consortium. Swedish researchers are relatively evenly distributed across the different types of instruments/techniques available at ILL, with a certain shift towards reflectometry, small angle scattering and inelastic methods.

Sweden is also funding a CRG (Collaborative Research Group) instrument at ILL: SuperAdam. SuperAdam is a neutron reflectometer operated by Uppsala University.

ISIS Neutron Spallation Source

ISIS is one of the world's leading neutron sources, located in the UK. ISIS has 35 instruments for neutron scattering at two target stations, as well as a facility for investigating materials using muon spectroscopy.

Sweden is participating in two of the instrument development projects at ISIS: upgrading the diffractometers Polaris and HRPD. This project is led by the Chalmers University of Technology in collaboration with researchers from Stockholm University and Uppsala University. Through the support for this project, Swedish users have had access to all the instruments at ISIS. Sweden is a scientific member of ISIS as of 2015.

MAX-lab and the MAX IV laboratory

Sweden now has a national synchrotron light laboratory, the MAX IV facility. The previous facility, MAX-lab, started receiving users in 1986, and will gradually be closing in 2015. The X-ray light of the new MAX IV laboratory,

which will be inaugurated in mid-2016, will have new properties, e.g., in the form of very high brilliance and coherence. The properties of the X-rays from the MAX IV facility are largely due to the magnet design developed at MAX IV. MAX IV will consist of a linear accelerator with a hard X-ray beamline in its extension for short (down to 100 femtoseconds) and highly intensive X-ray pulses, along with two storage rings run with energies of 3.0 GeV and 1.5 GeV respectively. MAX IV will therefore have its areas of strength at somewhat lower energies than Petra III and ESRF. When the MAX IV facility is completed in the mid-2020s, there should be approximately 30 beamlines to take full advantage of the investment in the two storage rings.

At present, the construction and funding of 11 beamlines have been decided. One of these beamlines is jointly financed by Finland and Estonia, and another by Denmark, while the rest of them are financed by the Swedish Research Council, the Knut and Alice Wallenberg Foundation (KAW) and twelve Swedish universities. Another three beamlines will be moved from the current MAX-lab to the new MAX IV, with support from the Swedish Research Council and KAW.

Architectural aerial view of ESS, MAX IV and Science Village Scandinavia in Lund. Image: ESS/Team Henning Larsen Architects.

Myfab

Myfab is a nationally distributed research infrastructure consisting of the three largest Swedish academic cleanroom nanotechnology laboratories; at Chalmers (the MC2 Nanofabrication Laboratory – NFL), KTH (the Electrum Laboratory) and Uppsala University (the Ångström Microstructure Laboratory – MSL). Work is underway to expand the infrastructure with another node, the Lund Nano Lab, in 2016.

Research conducted at this infrastructure include materials science, nanoscience, information and communication technology, bionanotechnology, life sciences, energy research and micro/nano systems. Myfab offers open access, education and process service to the academic sector, institutes and companies through more than 600 of the best equipment available when it comes to micro and nano manufacturing and specialised process lines. The various laboratories of Myfab are to a certain extent specialised in different areas of application and their related processes. The node at Chalmers focuses on the manufacturing of microwave, photonic and quantum components. The Electrum Laboratory, which is operated in close collaboration with the industrial research institute Acreo Swedish ICT, focuses on the manufacturing of semiconductor materials and components, wide bandgap silicon technology and the synthesis of nanomaterials. MSL focuses on material analysis, thin film technology, ion beam technology and the life sciences. Myfab has around 650 users from the academic sector (80 per cent), and 80 from companies and institutes (20 per cent) per year.

Petra III

Petra III is a German synchrotron light facility in Hamburg that opened in 2009, having previously been an accelerator used for particle physics. Like the ESRF, the Petra III ring runs at an energy of 6.0 GeV and the hard X-ray range is thus its area of strength. Also like the ESRF, Petra III supplements the MAX IV facility in that Petra III has a higher energy range that MAX IV will not cover. Sweden finances and is responsible for a materials science beamline, P21 (also known as the Swedish Material Science beamline, SMS). The energy range that can be used at the P21 beamline is 50–150 keV. The P21 beamline will have a substation for in situ diffraction and wide angle X-ray scattering (WAXS), without fully monochromatic radiation, as well as a main station for monochromatic diffraction. The P21 beamline will be available to users in early 2016. Thanks to the Swedish undertaking at P21, Swedish users also have access to the other instruments at Petra III through their user programme.

XFEL

XFEL is a spallation source being built in connection to an existing facility (Desy) in Hamburg, Germany. Since 2009, Sweden is a co-owner in the German company XFEL GmbH, which is responsible for the construction and owns the facility. The plan is for XFEL to be put in service in 2017. The machine will deliver energies of 17.5 keV (0.7 Å), at 27,000 femtosecond light pulses per second. This opens up new possibilities for research within materials science, structural biology and femtosecond chemistry. Several Swedish research groups are actively participating in the construction of XFEL.

Bilateral agreements

Röntgen-Ångström Cluster

The Röntgen-Ångström Cluster is a bilateral agreement between Sweden and Germany to strengthen research using neutrons and photons within materials science and structural biology. The agreement also aims to promote effective use of large facilities in the region (Sweden and northern Germany). The current agreement was entered in 2010, and a number of collaborative projects have been initiated so far. The funding from each country for the collaboration/research part is 3–4 million euros per year. In addition, Sweden will build and operate a beamline at the new German synchrotron PETRA III (see description above).

Franco-Swedish collaboration to develop a neutron instrument

As part of a larger bilateral agreement between Sweden and France, Sweden is contributing to the construction of two new instruments at Laboratoire Léon Brillouin (LLB) in Saclay (France): a SANS instrument and a spectrometer. These projects are underway from 2011 to 2016. Sweden finances parts of the upgrade, and Swedish researchers are offered the chance to work at LLB and participate in the development of instruments. As a result of the collaboration with LLB, a summer course in soft materials for doctoral students was carried out in 2013.

Strengths and weaknesses

Need for e-infrastructure within the field

The great need for e-infrastructure within the materials field has thus far arisen due to simulations and theoretical calculations. But changes are now being made within several research fields simultaneously, which will radically change these needs. At the same time, the needs for simulations and theory will remain, and continue to grow, both in scope and complexity.

The greatest change is driven by the development of new experimental methods, which generate large amounts of data. New detectors with improved dynamics and resolution, along with the ability of material analysis instruments to conduct time analysis and time structuring for an increasing number of phenomena, will lead to a dramatic increase in the amount of data. Processing these amounts of data puts higher demands on all levels of e-infrastructure: first in the early selection (enormous amounts of data that need to go through some form of early data processing), thereafter the transfer, for example via SUNET, and finally the storage, processing and analysis of data. The link to theoretical analysis, such as system dynamics, will be essential, as will image processing and visualisation of data.

This will place demands on computation capacity from groups that have not been major users of SNIC so far. This in turn leads to new requirements regarding the expertise provided by SNIC, training needs for researchers and new software. The possibility of remotely controlling various experimental stations at the large facilities in the future will place new and stricter demands on the networks and the quality of these services.

Synchrotron light

Synchrotron light is X-ray radiation produced in storage rings where electrons are circulating basically at the speed of light. The electrons are accelerated in order to generate a very intensive electromagnetic radiation, which can then be used to "image" various molecular structures. Synchrotron light has for several years been an established tool for advanced research in the fields of materials and materials development, structural biology, molecular structure chemistry, catalysis research, biogeochemistry, physics and nuclear chemistry. The technology has now also been introduced as a tool within fields such as medicine, biology and conservation. There is very strong activity within several of these fields in Sweden today. Swedish users can be

found both at the Swedish national infrastructure MAX IV in Lund, and at international synchrotron facilities such as ESRF (Grenoble, France), SSRL (Stanford, USA), Diamond Lightsource (UK), Soleil (Paris, France), Bessy (Berlin, Germany), DESY/PETRA III (Hamburg, Germany) and SLS (Switzerland).

Researchers from all over Sweden have also successfully participated in the construction of MAX-lab, which has resulted in a long tradition and high-level expertise within the field. The expansion of MAX IV provides excellent opportunities for a continued positive Swedish development within the traditionally strong areas (such as spectroscopy and macromolecular crystallography) It also opens up opportunities within new areas, such as coherence and imaging. Today, synchrotron light is used for biomedical imaging of tissues and cells, and for high-resolution determination of the three-dimensional structure of macromolecules (structural biology). This is of importance, for example, when it comes to investigating molecular mechanisms, and visualising the binding of drugs to the target protein. These experiments require the creation of macromolecular crystals, which is currently a limiting factor. In the future, the high brilliance and coherence of the beam at MAX IV will enable studies of smaller protein crystals. Monitoring very rapid biochemical processes in real time, for example how plants transform sunlight into energy through photosynthesis, will become possible.

It is important for laboratories and equipment at MAX IV to continue being adapted for questions from a wide range of subject areas, in order to fully utilise the facility's different possibilities. The technology behind the design of the MAX IV accelerator and storage rings has received great international attention, and all synchrotron light facilities being planned or upgraded will be using this technology. The synchrotron light facility ESRF, which will soon undergo the next upgrading phase, will have the same properties as MAX IV after 2019. In the next few years, Swedish researchers have a chance to take the lead by virtue of the experiences and skills developed in connection with MAX IV. This requires continuous strategic planning, long-term funding and national skills development at all levels. The planning needs to clarify which research areas are to be prioritised at MAX IV, and within what areas Swedish researchers should be referred to other facilities.

This will also require coordination between Swedish universities and MAX IV, so that education and practical training for postgraduate students as well as senior researchers can be arranged within all technologies that will be represented at the laboratory.

Infrastructure for neutron-based technologies

Neutron scattering is a technique in which neutron beams are used to study the structure and dynamics of different materials. One benefit of using neutrons instead of X-ray radiation is that lighter nuclei are detected much more effectively with neutrons. The importance of this method is increasing through increasing performance of the facilities, and it has gone from primarily being a tool for physicists to now having users evenly distributed over different disciplines: physics, chemistry, biology, materials science and conservation. The unique properties of neutrons are used, for example, to understand superconduction and the development of new materials for the electronics industry. The technology is also used to visualise the mode of action of enzymes, proton transport through biological membranes or protein-ligand interactions. Other examples include small angle scattering of neutrons (SANS) to study form and interaction in non-crystalline systems. Through its increased brilliance, the potent ESS facility will open up possibilities in the future for brand new experiments within the life sciences which have previously been impossible.

The Swedish user base is growing and is internationally competitive, which can be seen in the increasing allocation of beamtime at ILL. The Swedish use of neutrons, which has so far been primarily conducted at ILL and ISIS, is expected to continue increasing in the future. The Swedish users are evenly distributed over several disciplines, and considering the possibilities opening up to Swedish researchers due to ESS, there is a great need to train a new generation of Swedish researchers focusing on neutron scattering. More specifically, there is a need to increase the level of expertise within the development of instrumentation projects, so that Swedish researchers are able to participate actively in the construction of ESS, and thus be part of the first experiments. This skills development can be done through a combination of national and international recruitment of expertise, doctoral programmes and support for environments that are prominent today.

On the technical side, there is a great need for the development of detectors. On the one hand, detection needs to be optimised in order to increase the effectiveness of the experiments, but above all there is a need to find technologies that are not based on the use of helium – a product currently in short supply (and it will remain so) meaning that it comes at a very high price. Sweden, through Linköping University, is part of a very promising international development of thin film detectors, which is in the testing phase at ILL. With more effective detectors, covering wide solid angles, the processing of large data amounts will become an important question for neutron scattering as well.

Development of instrumentation and components

Swedish researchers are primarily involved as users of synchrotron and neutron sources today, and are generally very competitive when it comes to obtaining beamtime in open competition. As regards to technological development in infrastructures, Swedish research groups are less represented (with the exception of developing instrumentation at hard X-ray free-electron lasers, such as the XFEL). Participation in instrumentation projects (including development of detectors, components, software and analysis tools) yields benefits in the form of opportunities to be the first to conduct advanced experiments and have the knowledge required to optimise instrument performance and thereby break new ground.

The modern, third-generation synchrotron light facilities that MAX IV will belong to produce X-ray radiation of such high intensity that the detectors in many applications are unable to perform a linear measurement of the radiation intensity in the experiments. It is therefore of the utmost importance that new detector types are developed so that the extremely high radiation produced by the synchrotrons can be fully utilised. Research and development – primarily of X-ray detectors – must be given solid support in the future, and international collaboration within this area should be encouraged.

Mobility and career

World-leading infrastructures attract researchers from many countries, and are often the single most important reason for researchers to conduct all or parts of their research in a certain location. The fact that researchers get involved in the construction of joint national and international infrastructure is important for the research community at large, but it is problematic that the researchers who spend longer periods of time on the construction or operation of research infrastructures risk falling behind in their academic career. The same is true for researchers who spend a period working in industry and then want to get back to the academic world, as well as for researchers who spend a lot of time on collaboration or communication. It is of urgent importance for those working at the research infrastructures to have a solid connection to a university through secondment, thus having opportunities to get qualifications in terms of supervising and teaching.

Trends and tendencies

Synchrotron light facilities

The development at synchrotron light facilities around the world is guided by the local skills at the individual facility. The investments made generally have the objective to make the facility a world leader within a few technologies or applications within one or two current and well-defined research areas. Another trend is to conduct investigations *in situ* or *in operando*.

In later years, there has been a rapid development in the magnetic design of the storage rings, which has resulted in higher brilliance and smaller beams. The technical challenge for all synchrotron light facilities is now to achieve sufficient stability of the beamline optics. This is in order to enable measurements on very small surfaces and volumes (down to tens of nanometres) and an acceptable signal-to-noise ratio for applications where the desired signal is small in relation to the total signal, as in Röntgen-Raman. Certain synchrotron light facilities work intensively with the long-term stability and long-term supply of the delivered radiation. Another general problem is that existing detectors are currently unable to perform a linear measurement of the photon fluxes produced by modern synchrotron light facilities. Yet another rising problem is that there are currently no tools to easily process the large amounts of data produced. There is no hardware or software that handles this problem in a satisfactory way.

The research that generates the most publications is where experiment times are short, as in biocrystallography, X-ray microscopy and X-ray diffraction. It should be pointed out here that a high publication rate or publication in journals with a high impact factor are not the only measurements of high academic quality. Publication in high-quality disciplinary journals can be at least as valuable for academic knowledge development.

Free-electron lasers – FEL

The field of free-electron lasers is developing rapidly. The number of possible experimental stations is expected to increase within the next two to five years, however starting from a very low level. Stanford University is home to LCLS, the first hard X-ray free-electron laser. They are now constructing several beamlines and new types of experiments are being developed, while a second free-electron laser is being planned (LCLS-II). A European hard X-ray free-electron laser, XFEL, is also being constructed in Hamburg (ex-

pected to be operational in 2016). The DESY laboratory in Hamburg has the soft X-ray free-electron laser FLASH I (which is operational and continuously developed), and a second free-electron laser, FLASH II, will be put into service shortly.

Swedish researchers are highly involved in the field of FEL, and well-positioned internationally when considering the country's size. The number of Swedish users and developers within the field of free-electron lasers is relatively small, and they are mainly found within a couple of large research groups in Uppsala, Gothenburg and Stockholm. These groups are currently involved primarily in LCLS, FLASH I and the construction of XFEL. It will be possible to use the intensive, short-pulse and coherent beams from X-ray free-electron lasers for structural studies of biomolecules that are difficult to crystallise (femtosecond nanocrystallography) or which cannot be crystallised at all (imaging of single particles). The European X-ray free-electron laser XFEL will deliver a ten billion times more intensive X-ray radiation than what is available today in the form of ultra-short flashes at the femtosecond level. This opens up possibilities for a number of different experiments that could not be conducted before, and for brand new research questions within structural biology and medicine. Worth mentioning among the new experiments facilitated by the X-ray free-electron laser is the possibility of "filming" the atomic structure of a molecule or depicting single, living cells.

As the technology is relatively new, but with a great potential, research focusing on free-electron lasers should be supported. It is desirable to broaden the user base, and above all to get more research leaders within the field. The recommendation is to operate and support existing FEL infrastructure in the long term. There are also proposals and wishes to construct and operate FEL within Sweden. However, the technology is at an early stage, and international commitments should therefore be prioritised while national initiatives should be carefully considered. A review and follow-up of ongoing projects should be conducted in order to make a reasonable assessment of possible future FEL investments, both nationally and internationally.

Another relatively new technology is laser-driven X-ray sources, which in the future should be able to act as a supplement to other X-ray pulse characterisation methods.

Infrastructure for neutron-based technologies

Due to the increasing capacity of the leading neutron sources, the user base has been increased and deepened in terms of subjects, and now includes physical chemistry, engineering, biology, medicine and conservation. The

current users of neutron-based technologies are to a significant extent "expert users" or instrument developers. As the number of users increases and new user groups are added, support from experienced instrument researchers and developers at the facilities will be important to get started on experiments and data analysis.

In order to fully benefit from the coming ESS facility being built in Lund, it is important to prepare the Swedish researchers. It is important to encourage and support research projects using neutron scattering as a tool to work on problems within materials science and life sciences. Educational activities such as postgraduate programmes and support for young researchers to specialise in neutron-based techniques could increase the number of users and their collaboration. Through the agreements with ILL and ISIS, Swedish users have good access to neutron scattering, and these programmes should continue to receive a lot of support in the future.

An increased Swedish use of these facilities also entails a need for increased Swedish funding for the activities. A greater commitment in connection to the facilities within educational activities, doctoral and postdoc programmes is another effective way of reinforcing user collaborations.

Distributed infrastructures

Several of the methods used within materials science are organised through networks and infrastructures. The trend is increasingly large networks, and an internationalisation of these. There is a need to facilitate renewal of content and activities within these infrastructures.

Myfab

In terms of technology, there is currently a great pressure on high-resolution lithography equipment and electron microscopy. A clear trend, both nationally and internationally, is to link characterisation of materials and components to infrastructures for micro and nanomanufacturing. This is done to guarantee quick access to relevant methods and quality-assured processes, in part because the characterisation needs to be done in a cleanroom environment.

Organisationally speaking, there is a clear European trend of forming national networks or, as in the case of Myfab, distributed national infrastructures for nanotechnology facilities. These networks are now starting to interconnect at an international level. In this respect, Myfab has positioned itself well, for example through long-term collaborations with its sister organisation in Norway, NorFab, and the national infrastructures of Denmark (Danchip), Finland (Micronova), and France (RENATECH). When it comes to subject

areas, we see that Myfab is being used by an increasingly broad range of users; most of the new user groups now come from the chemistry sector and biosciences. This places new demands on a more flexible environment that can handle a large amount of new materials and an ability to train users with no background in micro or nanoelectronics.

Powerful imaging methods

Powerful imaging methods, using neutrons and X-rays, are currently available, and in a wider perspective they are relatively new in Sweden (whereas electron microscopy is a well-established research area in Sweden). These imaging methods have great future potential. It is important to now open up for subject areas that have not previously been using these methods.

An important trend within materials research is to custom-make materials (material synthesis) and components with atomic precision, which requires the ability to image and analyse them with atomic resolution. The development within transmission electron microscopy (TEM) is proceeding rapidly. A modern TEM instrument often combines several different technologies such as imaging, diffraction and spectroscopy, which all require a very high level of expertise in the user for the full capacity of the microscope to be utilised. National coordination is therefore very important in order to achieve maximal benefit from existing and future infrastructures, so that more researchers will be able to use advanced technologies at a high academic level in their research. The same situation may also apply to NMR and mass spectrometry.

Recommendations 2015–2020

Broad investments in research and technological developments in materials science

In connection with the large investments in materials science infrastructure that are currently underway, such as the construction of ESS and MAX IV, but also the Swedish commitment to XFEL in Hamburg, measures are needed to ensure optimal use of these facilities.

This means that it is important to find ways to support research in materials science, as well as young researchers and doctoral programmes, so as to benefit from the new opportunities offered by these infrastructures.

It also entails a need for support to technological development in the infrastructures, so that Swedish research groups can participate in this

(instrumentation projects, including detectors, components, software and analysis tools), particularly within synchrotron, neutron and free-electron laser technologies.

Review of the model for construction, renewal and decommissioning of distributed infrastructures

A review is needed of how distributed infrastructures are organised and renovated (for example through the creation of new nodes) with maintained scientific quality, focus and effective use of resources.

Utilise the possibilities of the MAX IV laboratory for Swedish research and development

Since Sweden is investing in a powerful synchrotron light source, it is also important to make sure that the full potential of the laboratory is utilised. This requires funding and prioritisation of research that allows Swedish research groups to compete internationally within the prioritised areas for a longer period of time. To make this possible, research, technology development and capacity building are required.

A continuous strategy and analysis effort, involving funding bodies as well as MAX IV, is needed to follow-up and develop the earlier strategy plan (from 2012). This work should aim to clarify which research areas are to be prioritised at MAX IV so that the facility can become, and remain in the long term, a world-leading infrastructure for research within these areas.

In connection to the construction of MAX IV, a solid plan for how to utilise and reinforces the expertise of staff and users at the facility will be necessary. Support for knowledge transfer and education will be of great importance for the effective use of MAX IV and for reaching new potential user groups. A skills development programme should be established, so that the sciences and methods where the unique properties of MAX IV, such as nanobeams, high coherence and extreme brilliance, are used to their full potential and are developed for top-class, international research.

The national strategic effort to gather national and international funding bodies must continue. Among other things, it is needed in order to find funding for more beamlines, so that c. 30 experimental stations can be completed around 2025.

Prioritisation of Swedish commitments in free-electron laser infrastructure (FEL)

Free-electron laser infrastructures are of great importance to Swedish research. Existing Swedish commitments to such infrastructure, for example in XFEL, should also remain a priority.

A review and follow-up of ongoing projects should be conducted in order to assess possible future FEL investments, both nationally and internationally.

Utilise the opportunities presented by ESS to Swedish research by capacity building

Sweden will host the great pan-European research laboratory ESS, and it is of the utmost importance that the Swedish research community is prepared for this upcoming opportunity. Expertise relating to the use of neutron scattering technologies and the development and construction of instrumentation should be developed in order to fully utilise this opportunity. This can be achieved by enabling Swedish researchers to participate in instrumentation projects (ESS, ISIS, ILL), doctoral programmes, international recruitments and through support to strong environments. The international agreements entered with Germany (RÅC), France (LLB) and the United Kingdom (ISIS) should be used for this purpose.

Training initiatives and career paths at nationally and internationally important infrastructures

The infrastructures' responsibility for follow-up of training initiatives needs to be made clearer. It is important for the infrastructures to regularly offer courses, partly providing a theoretical background for the experiments that can be conducted at the infrastructure in question, partly with practical training elements on safe and correct use (regardless of whether there is staff performing the experiments or not), and partly providing knowledge and training for analysing the data produced by the experiment.

Within materials science, for example, training initiatives are needed to develop knowledge and promote the use of different imaging methods, which from a wider perspective are relatively new in Sweden. This applies to visualisation within microscopy, MRI and tomography with different imaging methods within synchrotron light and neutron scattering. This is needed in order make it accessible for subject areas that have not previously been using these methods. For this reason, skilled staff must be recruited and modern equipment installed, and training in the form of doctoral

programmes and trainee programmes – as well as expert and user support – is needed.

Sweden has invested, and continues to make big investments, in the construction and operation of world-leading (nationally important) research infrastructures. Hence, there is also a need to ensure that both Swedish and international researchers get involved in the construction and expertise at these facilities. The researchers who are involved in these projects, or actively involved in the infrastructures, need to get recognition for their work, as well as opportunities for academic qualifications in the form of secondment, for example.

Improved processes for prioritisation and selection of Swedish commitments

The Swedish commitments in international infrastructures, particularly within the areas of neutrons, synchrotrons, and free-electron lasers, should be focused on a limited number, to enable long-term investments and clear influence over the activities. Efforts will have to be made to develop clear priorities when it comes to infrastructure investments, both nationally and internationally.

Need for new material analysis infrastructures

It is necessary to investigate the need for national coordination of equipment and materials analysis through microscopy (such as TEM and SEM) and spectroscopy (such as NMR and mass spectroscopy).

PHYSICS AND ENGINEERING SCIENCES

Description of the field

Joint research infrastructures were first developed within the physics field, among other reasons to find answers to questions relating to the origins of the universe and the nature of matter. As the facilities required have become increasingly large, they have also become too extensive and expensive for a single university or even a single country to develop, which is why researchers often collaborate nationally or globally to construct and operate the facilities needed to make progress.

When it comes to physics today, it is still primarily within the fields of astronomy, subatomic physics and ion physics that national and international research infrastructures exist to a greater extent. The research in these fields is often entirely dependent on having access to large international infrastructures. Within the engineering sciences, there are still research infrastructures at the regional level to a greater extent. Large infrastructures (such as MAX IV and ESS) are also being used by other disciplines within physics, such as materials physics and atomic and molecular physics. These are described in other parts of the guide (see the chapter on materials science). The review in this chapter is therefore devoted primarily to astronomy, subatomic physics and ion physics, and to a lesser extent to engineering sciences.

Astronomy strives to increase our understanding of the physical processes taking place in the universe, from planets to the universe as a whole. Traditionally speaking, astronomy has grown out of studies within the fields of radio waves and visible light, however, in later decades observations from other wavelength areas have also come to take a central role. Within all areas, observations from telescopes on Earth and in space supplement one another, but the parts based in space will not be described in more detail here, as they are managed by the Swedish National Space Board. The infrastructures that are now being planned are driven by fundamental questions such as the formation of the first galaxies in the distant universe, the existence of earth-like planets and markers of biological activity on other planets.

Within particle physics research is conducted in order to understand the smallest building blocks of the universe. The discovery of the Higgs particle at CERN confirmed the so called Standard Model (theory of particle physics), however, a number of questions remain for which the Standard Model provides no answer. Several of these are linked to the development of the universe,

such as the questions of what dark matter is and why the universe contains mostly matter and hardly any antimatter. The Standard Model is also unable to explain why neutrinos have a mass.

Astroparticle physics attempts to answer questions from both particle physics and astrophysics with the help of protons, neutrinos and photons, which are observed in different types of detectors. The central goal of this research is to examine cosmic particles and their origin in the universe. Swedish ground-based research within astroparticle physics focuses on cosmic neutrinos and gamma radiation.

Nuclear physics contains the study of atomic nuclei, their components, structure and dynamic, as well as the fundamental forces acting on and within them. Developments within nuclear structure physics are heading towards using beams of short-lived radioactive isotopes to study atomic nuclei with an extreme relationship between the number of neutrons and protons. There is also a direct link to nuclear astrophysics, where processes often involve instable nuclei. Hadrons is a collective term for all particles consisting of quarks. Exactly how the simplest bound systems of quarks are constructed is still unknown, and this is what hadron physics studies by looking at short-lived particles formed during collisions. Within ion physics, detailed studies are conducted of how charged atoms or molecules interact with one another.

In common for all the experiments within particle, nuclear, hadron and ion physics is that they all depend on particle accelerators, often located at large international laboratories. Particle accelerators were developed for the specific purpose of studying the inner structure of matter. The development of accelerator technologies at national and international laboratories has benefited a number of other research fields, such as cell and materials research and medical radiotherapy.

Engineering sciences is a field that includes both basic research and application. It consists of a number of different research subjects; in common for all of them is that they strive to apply basic research and predict process outcomes and functions of products. Research infrastructures within engineering sciences are often dedicated to a certain field. The researchers also use some of the large infrastructures described in other parts of the Swedish Research Council's Guide to Infrastructures, such as synchrotron light and neutron scattering facilities.

Infrastructure financed by the Swedish Research Council

CERN

CERN (Organisation Européenne pour la Recherche Nucléaire (European Organization for Nuclear Research)) is a convention-bound organisation that runs the world's largest particle physics laboratory, located outside of Geneva, on the border between Switzerland and France. Sweden was one of the twelve founding countries when the organisation was formed in 1954; making CERN the first major international research infrastructure. CERN currently has 21 member countries, primarily in Europe, but the facility is used by researchers from all over the world. CERN is governed by a council consisting of member country representatives. In accordance with the convention, the CERN Council is also tasked with developing the European strategy for particle physics. In addition to particle physics research, accelerator and detector development is also conducted at CERN. Furthermore, research on a smaller scale is conducted within nuclear physics, biomedical engineering, materials physics and e-Science. The Large Hadron Collider (LHC) and the LHC experiments are the projects with the highest priority at CERN, with an upgrade of LHC being planned in the early 2020s.

The research conducted at LHC is unique and world-leading; particle physicists from all over the world participate in these experiments. Swedish researchers are involved in two of them: ATLAS and ALICE. These experiments are semi-autonomous and monitored by a board consisting of representatives for the various institutions tied to the experiments. They are funded in part by CERN, but mainly through direct funding from the countries participating in the experiments, in Sweden's case through the Swedish Research Council. The budget for the experiments is decided by a committee with representatives for all the financiers.

CTF3 is a testing facility at CERN that was built as part of the accelerator research in preparation of a possible new accelerator called CLIC. This testing facility receives an operational grant from the Swedish Research Council, and is governed in the same way as ALICE and ATLAS.

The ISOLDE facility at CERN delivers radioactive beams for research within fundamental nuclear physics, as well as fields such as nuclear astrophysics, studies of the weak interaction and condensed matter physics. ISOLDE has traditionally had a clear Scandinavian profile, and Sweden has been involved since the start.

DESIREE

DESIREE (Double ElectroStatic Ion Ring ExpEriment) is a facility for atomic and molecular collision physics at Stockholm University. It consists of two overlapping storage rings that can store beams of atomic and molecular ions, the latter consisting of anything from simple molecules to complex biomolecules. Using DESIREE, it is possible to study processes in fundamental atomic and molecular physics, as well as applications in fields such as laboratory astrophysics and biomolecular physics. DESIREE has been under construction for a number of years, and is now close to the experimental phase.

ESO

ESO (European Southern Observatory) is a convention-bound international organisation for astronomy research that Sweden has been a member of since its creation in 1962. Today, it consists of 15 member countries, and the Swedish Research Council represents Sweden in the governing bodies. ESO headquarters are located in Germany, but the observatories La Silla-Paranal and ALMA are in Chile.

At La Silla and Paranal, there are a number of larger telescopes for observations in the visible and infrared light, including the VLT (Very Large Telescope), which consists of four 8.2-metre telescopes. ALMA (Atacama Large Millimeter/submillimeter Array) consists of 66 interconnected radio antennas, and is a partnership between primarily ESO, USA and Japan. ALMA is also home to the APEX telescope, a collaboration between ESO, the German Max Planck Institute for Radio Astronomy and the Swedish Onsala Space Observatory.

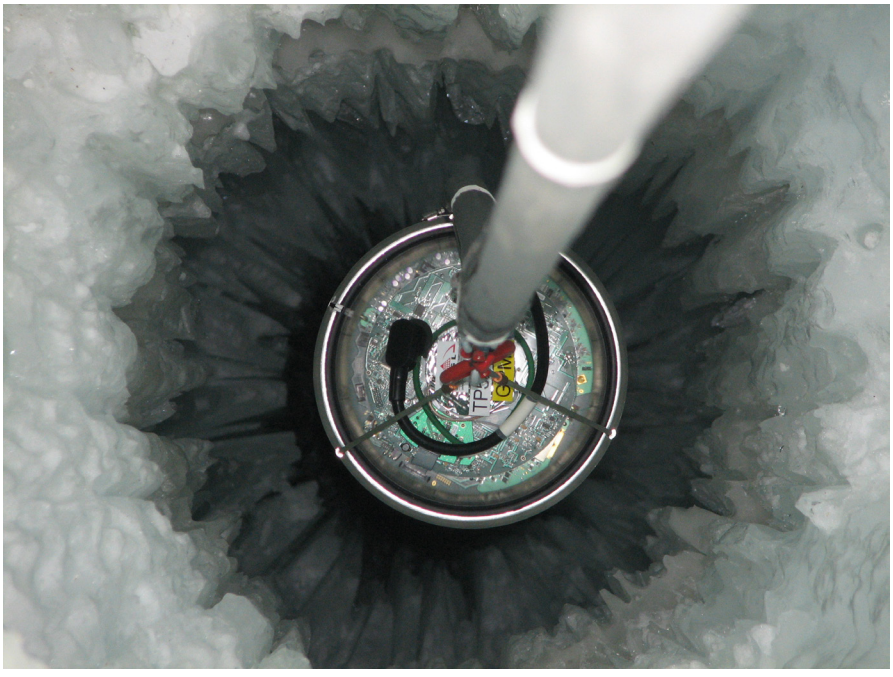
Research conducted in Sweden with the help of ESO's facilities span all the major questions of modern astronomy, such as the formation and development of galaxies, stars and planetary systems, and studies of extreme relationships in the universe such as gas streams around black holes.

ESO's highest priority within the next few years is to construct the world's largest telescope for visible and infrared light; the E-ELT (European Extremely Large Telescope). This telescope will have a 39-metre main mirror, and will be completed at the earliest in 2023. Observations using the E-ELT will contribute to answering questions regarding planets beyond our solar system, and monitor the emergence of large-scale structures in the universe.

FAIR

FAIR (Facility for Antiproton and Ion Research) is an accelerator facility for nuclear, hadron and ion physics. The facility is under construction in connection to the research facility GSI in Darmstadt, Germany. FAIR is being constructed within the scope of an international convention, and is owned through a German company with international shareholders, currently nine countries and one associated partner. Sweden signed the convention in 2010, and through a consortium with Finland, the Swedish Research Council owns shares corresponding to 1.5 per cent of the capital. The member countries contribute both cash funds and equipment.

FAIR is governed through a council with representatives for the member countries. FAIR has been developed as a user-driven project, with a strong involvement from the future users. The operational costs, and how these are to be distributed, are currently being negotiated by the member countries.



The IceCube Neutrino Observatory is the world's leading neutrino telescope and consists of light-sensitive detectors placed deep in the ice of Antarctica. Image: IceCube/NSF.

IceCube

The world's leading neutrino telescope, the IceCube Neutrino Observatory, consists of light-sensitive detectors placed deep in the ice of Antarctica, taking up a volume of one cubic kilometre. The central goal of this detector is to study high-energy neutrinos – a type of elementary particles that are difficult to detect – from space and their astrophysical sources. Neutrino oscillations are also studied with the help of atmospheric neutrinos. IceCube has recently detected the first high-energy cosmic neutrinos.

Belgium, Sweden, Germany and the USA started IceCube, and at present, twelve countries are participating. The four founding countries monitor the project through a control group, in which the Swedish Research Council is represented. The observatory is funded in great part by the American research council, the National Science Foundation, but also receives funding from the Swedish Research Council.

ISF

The Institute for Solar Physics (ISF) operates the Swedish Solar Telescope on the Canary island of La Palma. The institute is a national infrastructure hosted by Stockholm University. This world-leading facility has contributed important information for our understanding of the sun. The research is aimed at understanding the structure and dynamics of the sun's atmosphere.

NOT

NOT (Nordic Optical Telescope) is a joint Nordic telescope on the island of La Palma. NOT is controlled by NOTSA (the Nordic Optical Telescope Scientific Association) Council, where the Swedish Research Council represents Sweden. All the Nordic countries contribute to the funding through their national research councils. Over the years, Swedish astronomers have used a number of instruments at this telescope, in later years primarily for observations of supernovas and galaxies.

The Swedish Research Council (RFI) made a strategic decision in 2010 to support Swedish participation in the construction of the ESO telescope E-ELT. Consequently, the RFI decided to gradually disengage from NOT. Two years after a decision to construct the E-ELT, Sweden will thus begin to phase out its support for NOT. The definitive decision of the ESO regarding the construction start for E-ELT was made in December 2014.

Onsala Space Observatory

The Onsala Space Observatory is a Swedish national facility hosted by Chalmers. The observatory constructs and operates astronomy and geodetic infrastructures, both on site in Onsala and internationally. The astronomy research at Onsala deals primarily with the use of radio astronomy technology to study different aspects of the universe. The research is mainly focused on studies of the interstellar medium and its fundamental importance for the development of the universe – from planetary systems to cosmology.

At Onsala, there are two parabolic antennas (20 m and 25 m in diameter), which are used for single observations and for interferometry, together with radio telescopes around the world, through the European institute JIVE (Joint Institute for Very-long baseline interferometry in Europe). In 2015, JIVE will be organised as an ERIC under the name JIV-ERIC. In addition, Onsala has a station constituting a part of the international LOFAR network – a predecessor of the SKA project.

Onsala is the host of the Nordic ALMA ARC node, which is to support Nordic use of ALMA (more information under ESO). The observatory is also responsible for the Swedish part of APEX (see above under ESO). The national facility also conducts advanced instrument development for radio astronomy.

The Onsala Space Observatory has also been used for several years by the national and international research communities within earth sciences. The Onsala Space Observatory is a geodetic fundamental station and part of the international station network of the international Terrestrial Reference Frame, contributing to international collaboration, for example in the International Earth Rotation and Reference Systems Service and the Global Geodetic Observing System. The instrumentation at Onsala that is supported by the Swedish Research Council is used, among other things, for research on frames of reference and the earth's rotation and gravitational field, variations in the composition of the atmosphere and sea level measurements.

Description of potential new infrastructure

CTA

CTA (Cherenkov Telescope Array) is a planned infrastructure for high-energy astrophysics and astroparticle physics. The EU is currently funding the preparatory phase. The CTA consists of a number of Cherenkov telescopes that

are to be built either in Namibia or Chile. There are also plans for a facility in the northern hemisphere. Research that would be enabled through the CTA focuses primarily on high-energy astrophysics, cosmic radiation and dark matter. The CTA is a priority in the roadmaps from ASPERA, ASTRONET and ESFRI.

SKA

SKA (Square Kilometre Array) is an international radio astronomy project currently involving 19 member countries. It will consist of a number of interlinked radio telescopes in South Africa and Australia. The Onsala Space Observatory is involved in the planning and development of SKA, which gives a potential for Sweden to play a prominent role in the project. The roadmaps from ASTRONET and ESFRI give E-ELT and SKA joint highest priority.

SKA will be constructed in phases, and the first part, SKA-1, will be completed in the early 2020s, taking up 15–20 per cent of the final collecting area. Despite its limited surface, SKA-1 will have a much higher sensitivity than today's radio telescopes, and it will also be significantly faster. SKA has a very broad academic programme, including studies of the reionisation of the universe, the development of galaxies, gravitational waves and prebiotic molecules.

Strengths and weaknesses

Astronomy and subatomic physics

Swedish research within astronomy and subatomic physics is often completely dependent on access to large research infrastructures. There is therefore a longstanding tradition of working with international infrastructures, which in turn has led to extensive international collaborations and, at the same time, a high degree of national coordination within most areas.

Swedish astronomy is internationally prominent, both in terms of theoretical and observational activities. The observation-based activities are completely dependent on Swedish researchers having access to large international infrastructures. In large part, this need is met through the Swedish memberships in ESO, NOT and ESA[14], the national facilities ISF and Onsala,

14 The ESA (European Space Agency) provides research infrastructures based in space. The Swedish membership in the ESA is managed by the Swedish National Space Board.

and the open time policy of many facilities: the facilities where Sweden is a member providing researchers from non-member countries with the possibility of using the facility in return for Swedish researchers getting access to infrastructures in which Sweden is not a member.

Astronomy research in Sweden has no national coordination, researchers instead apply for time slots in open competition. The different universities have their own, clear research profiles, and at the national level there is good knowledge of the activities and their prioritisations. However, Swedish use of certain infrastructures is sometimes at a low level compared to the financial share, which is probably due to the breadth of Swedish astronomy research, and the possibility to use infrastructures that are not funded by Sweden.

Astroparticle physics in Sweden is traditionally linked to the neutrino experiment IceCube and its predecessors, where Sweden has had a very prominent role since the start. Prominent Swedish research within astroparticle physics has also been conducted for some time with space-based instruments, and ground-based Cherenkov telescopes. Astroparticle physics has expanded as a research field since the 1990s and the number of Swedish researchers has increased since then. The Swedish researchers are successfully involved in several infrastructure projects, which means that supplementary information can be gathered from different particles and wavelengths. To improve the national coordination, it would however be desirable for the research community to establish a forum where prioritisations within astroparticle physics in Sweden can be discussed.

When it comes to subatomic physics, Swedish researchers have been highly visible in the large experiments they participate in, as well as in the development of the actual infrastructures. Within the experiments, they have contributed to research results at the forefront of the activities. They have also contributed to the construction of the experiments and the establishment of e-infrastructure.

The activities within this area has been concentrated to a few large international accelerator facilities. All Swedish research within particle physics is for example conducted at CERN. This concentration has led to increased coordination between the Swedish research groups, and a stronger focus on a few leading projects.

A general characteristic that is particularly discernible within nuclear and particle physics, but also within parts of astroparticle physics, is the great number of authors per publication. This characteristic entails difficulties for individual researchers to profile themselves, and makes it problematic to compare the subject to others.

Even if membership in large international infrastructures provides Swedish researchers in the field with unique opportunities for successful careers, there is a problem with participating in the actual construction of the infrastructures. The construction process is long (usually more than 10 years) and generates few publications whilst underway. It is therefore risky for younger researchers without permanent employment to get involved in this process. In astronomy, this has resulted in a low level of participation in the construction of infrastructures. However, one exception is the Onsala Space Observatory, where the existence of on-site radio telescopes, along with the technical research on detectors conducted at Chalmers, also contributes to a successful participation in international infrastructures within the field of radio and IR. Within subatomic physics, Swedish researchers participate to a greater extent in detector development, but since this does not generate publications, it is important for the researchers to also have opportunities to participate in experiments at other research facilities. This is particularly true for younger researchers.

It is important that the large investments made in the international infrastructures are followed-up with employment initiatives, so that these facilities can be used by Swedish researchers. To give an example, the earlier investments made by the Swedish Research Council in researcher positions has been a great support in recruiting talented young researchers. The career opportunities at Swedish universities are determined by the universities, and it is therefore important to have an understanding of the activities at large international facilities. An improved dialogue between research-funding bodies and universities would therefore be desirable. In addition to researcher positions, resources are needed for travel to the international facilities, and also to station researchers. Researchers and engineers currently receive remuneration from the Swedish Research Council for travel and work that is part of the operation. In order to remain visible and make a career at these infrastructures, it is also necessary to also participate in other parts of the activities. It is only possible to get funding for this by applying to the Swedish Research Council's Scientific Council for Natural and Engineering Sciences. The situation today, with very few grants, is of concern.

When new services and materials are to be procured at large international infrastructures, the procurement takes place in the various member countries. In many cases, Sweden has a disproportionately low level of industrial returns in relation to the member contribution to the infrastructure. Sweden thereby misses out on the knowledge transfer and employment opportunities that these contracts contribute to. Hopefully, the Industry Liaison Office (ILO) function at the new business secretariat soon to be established at Vinnova

will improve this situation.

Positions for staff at international infrastructures are generally advertised in the member countries. In this respect as well, Sweden often has a disproportionately low level of positions in relation to the member contribution paid to these facilities.

When it comes to the administration of memberships in the large international infrastructures, a recurring problem is fluctuating exchange rates that lead to large variations in the annual member contributions.

Engineering sciences

Engineering sciences has traditionally been a strong field in Sweden for a long period of time. Sweden has broad, industry-related research, and over time the industry has come to appreciate academic research, and employs doctoral graduates to a greater extent than previously.

There are no ongoing operational grants paid to research infrastructures within the engineering sciences, however, other existing infrastructures are being used within this field. This is probably a result of the infrastructures available on this field often being of a regional nature, and fairly specialised within a narrow area, which means there are not as many facilities being used by several different research groups nationally. An increased national coordination would be desirable, and the Swedish Research Council could play a part in this.

The operations of Swedish companies are to an increasing extent being moved abroad, as the companies are purchased by larger, foreign stakeholders. This can be seen as a weakness for the field, but in many cases it results in the companies finding it increasingly important to keep their research activities in Sweden. In this respect, Sweden needs to invest in research to remain a strong contender in the field of engineering sciences.

Need for e-infrastructure

A common factor for all the described infrastructures within subatomic physics and astronomy is that they all produce enormous amounts of data that has to be processed and analysed. A strong and well-developed e-infrastructure is therefore an absolute necessity for research to be conducted within this field. Without such infrastructure, Sweden would have limited opportunities to make any significant contribution to research. The requirements for high-performance computing (HPC), data storage and high-speed data links are therefore very high, and are expected to increase in the coming years.

The need for HPC is estimated to increase on average at a factor of five in the next few years, but this of course varies between different fields. The demand for HPC is so high within certain fields that it can essentially be described as unlimited. Each given increase of computing capacity can therefore be used immediately, as the precision of the calculations can be increased. An increased computing capacity can also give rise to opportunities to ask new questions, which are currently impossible due to limited capacity. The need for network speed is also expected to increase dramatically, particularly within observation-based astronomy.

The time scales for experiments within subatomic physics and astronomy are usually very long, and the instruments built are often very expensive and complex. Physicists have therefore been pushing the development of grid technology, and Swedish researchers have been actively involved in this development, at the European level as well as the Nordic and national levels. New investment in research infrastructures within astronomy and subatomic physics will furthermore require extensive development of fast data networks, hardware, data storage and grid technology.

Within engineering sciences, there are also great needs when it comes to advanced user support and code development.

Trends and tendencies

In common for the entire subject area is that the development is to a large extent controlled by international trends and tendencies, possibly with the exception of parts of the engineering sciences field.

Astronomy

Within astronomy, new instrumentation with better resolution and broader wavelength intervals are constantly contributing to an increased understanding of the often complex physics from small scales (planets) to the largest (galaxy clusters). Large investments such as the Very Large Telescope (VLT), the James Webb Space Telescope (JWST) and SKA have been motivated to a large extent by studies of objects in the early universe. In later years, exoplanets have become a rapidly growing branch of astronomy, and the design of E-ELT

ALMA will be the world's most powerful telescope for studying the Universe at submillimetre and millimetre wavelengths, on the boundary between infrared light and the longer radio waves. Image: ESO/B. Tafreshi (twanight.org).

not least has been affected by the technical requirements for studying exoplanets. Another trend is larger mapping projects, where large amounts of data are collected by research consortiums rather than by individual research groups. As an example, the GAIA satellite and its supporting projects can be mentioned. Even if most of the time at observatories will still be used by individual research groups (around the size of ten people), there is a tendency for the proportion of large projects to increase, as the new telescopes become larger, but fewer in number. A future branch with great potential is the search for biomarkers, i.e. life on the exoplanets. This branch includes future satellite observations in the conceptual stage, however, SKA also has the potential for important discoveries within the field.

At the end of 2010, the Swedish Research Council made a strategic decision regarding Swedish participation in the giant European telescope E-ELT. The project is run by ESO, and a decision regarding construction was made in December 2014. The telescope is estimated to be operational at the earliest in 2023.

New investments mean that some previously relevant infrastructure should be phased out. An example of this is the Swedish Research Council's decision to gradually disengage from NOT. However, the importance of VLT will remain, as the E-ELT will not be doing everything, but will only be used for the projects that require a 40-metre mirror. The Swedish Solar Telescope is expected to continue playing an important role until the planned European Solar Telescope (EST) is completed.

ALMA and SKA will be the dominating instruments within radio astronomy in the future. For this reason, the astronomic activities at Onsala should primarily be targeted to these facilities in order to support, operate and to some extent supplement them. Today, the Very Long Baseline Interferometry (VLBI) is an important activity at Onsala, which can also supplement SKA with an extremely high spatial resolution.

Astroparticle physics

In the field of astroparticle physics, great strides have been taken in neutrino astronomy, due to the discovery in 2013 of high-energy astrophysical neutrinos at IceCube. In order to interpret this discovery, an increase in the detector volume is required. An expansion of the detector towards low energies (PINGU) is also being planned, primarily for studies of neutrino properties, but also for the search for dark matter.

Swedish researchers have been actively involved in IceCube since the start, and are not participating in the planned neutrino project KM3NeT that has been prioritised by ESFRI. However, IceCube and KM3NeT have initiated collaborations within the Global Neutrino Network (GNN).

In addition to observations in space, supplementary information is provided by Cherenkov telescopes, both in terms of dark matter and the origins of cosmic particle radiation. The planned CTA is expected to be the next major infrastructure within this field.

Particle physics

The CERN Council set the European Strategy for Particle Physics in 2013, in which the upgrade of LHC has been given the highest priority. This means that within particle physics, both in Europe and in the rest of the world, LHC will dominate the infrastructural needs over the next five years. LHC will reach its full energy in 2015, and Swedish researchers will continue to conduct research at the ATLAS and ALICE experiments. Extensive upgrades will also be made in the early 2020s, but research and development is already underway in preparation of this project, in which Swedish researchers are participating. The Swedish Research Council has funded the de-

velopment efforts, but the costs of the actual upgrade remain to be settled.

The discovery of the Higgs particle has led Japan to plan a new accelerator with the aim of studying it. In both Europe and the USA, the participation in this project has been given high priority. This accelerator, if it is built, is estimated for completion in 2030. Another priority area is neutrino research, where projects to study the properties of neutrinos are in the planning stages. Research and development on the next generation of accelerators, where the Compact Linear Collider (CLIC) is one alternative, is also an important activity.

Nuclear, hadron and ion physics

When it comes to Swedish nuclear and hadron physics, FAIR and the experiments that will be built there are of the highest priority, and Swedish groups are putting a lot of effort into planning and completing detector components within the construction period. The first experiments at the starting version of FAIR can begin at the earliest in 2019, which means that some existing infrastructure will be important in the next few years. For Sweden, the facilities at RIKEN (in Japan), GANIL (Grand Accélérateur National d'Ions Lourds, France) ISOLDE and BEPCII (Beijing Electron–Positron Collider II, China) are the most interesting, and instrumentation that is primarily intended for use at FAIR (such as AGATA and CALIFA) may come to be tested and used there during the construction of FAIR.

The FAIR start version is limited, which means that only part of the infrastructure's full potential will be utilised at first. The complete facility will be constructed gradually over the first half of the next decade. Not only will this mean further opportunities to broaden the academic programme, but also that the effectiveness increases dramatically.

The Swedish facility DESIREE, which utilises low-energy ions, has the potential of becoming a world-leading facility. A gradual development of the national and international user bases, as well as the academic programme, will take place in the next few years.

Engineering sciences

Trends and tendencies within engineering sciences can often be attributed to interdisciplinary trends, and to tendencies within the subject areas where applied research is conducted. To counteract the risk of decreasing industrial production in Sweden in the future, we should invest in engineering science research. This research is an important link between basic research and applied product development.

In the area between engineering sciences and energy research, there are several investments in alternative energy sources, including green fuels, wind and wave power. Traditional energy forms also require research, and within hydropower – an area of great importance for Sweden – research into new and more effective turbines and generators is currently underway.

When it comes to transport technologies, Sweden has long been conducting prominent research. An example of interesting future areas are testing tracks for railway transports and electric roads, automatic vehicles and dynamic vehicle testing.

An interesting area within production engineering is additive manufacturing (often referred to as 3D printing), where Sweden is at the forefront of the technological development. Rapid progress is being made within this area, both in research on possible new material systems to use and new application areas. On the procedural side, work is done to increase tolerances and volumes that can be produced.

Recommendations 2015–2020

Astronomy and astroparticle physics

Continued membership of ESO is a requirement for Sweden to continue conducting first-class research within astronomy. The ESO telescopes VLT and ALMA will continue to be of great importance to Swedish researchers over the next few years. Further down the road, the planned telescope E-ELT will play a very prominent role.

The Onsala Space Observatory will remain an important Swedish radio astronomy node. The international facilities in which Onsala operates, primarily ALMA and SKA, should be given a higher priority in the long term, above the astronomy-related observation activity on site.

Sweden currently holds a position as a world-leader within observational solar physics, thanks to the Swedish Solar Telescope (SST) in La Palma, which has the highest spatial resolution of all solar telescopes in existence. The SST will remain the most important solar telescope until the next generation of large telescopes, the American DKIST and the European EST, are completed sometime in the next decade. Continued support to ISF is necessary to maintain Sweden's strong position within solar physics.

Swedish researchers have prominent roles within the IceCube project, and continued support for this operation is recommended. There are plans to develop IceCube by expanding the telescope for both higher and lower energies, but the details of what the Swedish involvement in this would be are still unclear.

Swedish researchers have been receiving project planning grants from the Swedish Research Council to prepare a possible Swedish membership in three new major international infrastructure projects: CTA, EST and SKA. Out of the new projects that have received project planning grants from the Swedish Research Council, the highest priority is given to SKA, but CTA is also of great national interest. The roadmaps from ASTRONET and ESFRI combined give E-ELT and SKA the highest priority. Swedish participation in EST is a condition for maintaining Sweden's strong position within solar physics, but the planning at the European level has halted in recent years, and an investment decision is a few years away. The Swedish Research Council should keep the project in mind for the future.

Subatomic physics

Continued membership in CERN is a condition for Swedish particle physics, where the LHC will remain unchallenged as the most important priority during the time period in question. In the early 2020s, extensive upgrades will be made to the LHC in order to increase the number of collisions per unit time inside the detectors. This also requires the experiments ATLAS and ALICE to be upgraded. If Swedish researchers are to continue as members in these experiments, and as active researchers within experimental particle physics, they must also participate in the upgrade of ATLAS and ALICE.

Within nuclear and hadron physics, the highest priority is to complete the FAIR facility and its experiments. As the FAIR start version will not be operational until 2019 at the earliest, activities at other infrastructures will be important, for example at the ISOLDE facility and the AGATA detector at GANIL. A gradual expansion of FAIR beyond the start version will take place from 2020 and on. Before then, the Swedish researchers involved will need to plan upgrades of the instrumentation to match the increased opportunities created through the construction of the complete facility.

The national infrastructure DESIREE will become increasingly relevant when it comes to ion, atomic and molecular physics within the next few years, as full utilisation of the facility approaches. However, it is important

to strengthen the national and international user base. As of now, it appears highly reasonable to continue supporting DESIREE at an adequate level, so as to realise the full potential of the facility.

General recommendations

Participating in international infrastructure projects affords Swedish researchers opportunities to be involved in the development of instruments and technology, both in the actual construction of instruments and the development of analysis tools and supporting software. There is development potential here, especially with coordinated initiatives from authorities and industry

Coordination within engineering sciences

Within the engineering sciences, there is a great need for increased national coordination, as this only exists to a smaller extent. Today, there are islands of infrastructure at the various higher education institutions, but it is not certain that everyone is aware of what facilities are available. The Swedish Research Council can play a large role in the coordination of the Swedish infrastructures, by investigating the possibilities for national infrastructures, and by initiating a dialogue with the researchers involved in engineering sciences, the technical universities and funders within the field.

Need for supporting e-infrastructure

New investment in research infrastructures within astronomy and subatomic physics will furthermore require extensive development of fast data networks, hardware, data storage and grid technology. There is no single computer architecture that is optimal for all research facilities. Swedish researchers should instead continue to be offered a wide spectrum of computer resources. These can include fast networks, traditional supercomputers, massive parallel processing, grid resources and possibly distributed systems that take advantage of inactive work stations.

The engineering sciences have a great need for supporting e-infrastructure in the form of code development and advanced user support. Advanced e-infrastructure, such as high performance computing clusters, should also have application in engineering science research into these infrastructures. Just as within the subject area itself, there is a need for national coordination here.

ENERGY RESEARCH

Description of the field

The development of a long-term sustainable and secure energy system is one of the greatest challenges for the global community. There is a clear link between a society's per capita energy use and the development of its material wealth. The world's energy systems are currently strongly interlinked, and undergoing a phase of rapid development. Fossil fuels continue to be predominant in the world's energy supply, with approximately 85 per cent of commercially traded energy. The majority (around 60 per cent) of the world's electricity is produced from black coal and natural gas, and the use of fossil fuels increases drastically from year to year. At the same time, there is a growing concern for how this use may come to affect the climate through an amplified greenhouse effect. There are heightened demands to increase the proportion of renewable energy, both nationally and within the EU. Another clear trend is that many countries, for geopolitical reasons, are concerned about their dependence on imported energy. Some countries, including Finland, are investing in new nuclear power plants, but the Fukushima accident has led to strong questioning of this form of energy. It is unclear how future solutions for the energy supply issue will be formulated, particularly in the medium and long term. There is thus strong motivation for research initiatives within multiple areas.

Biomass is already used to a great extent as a source of energy. More than 30 per cent of the added energy in Sweden comes from biomass, i.e. from the forest. There is a global shift from simple to more high-tech use of resources. There is a large but untapped potential for this, for example in Sweden, even if biomass is not expected to solely replace fossil and nuclear fuels. Globally speaking, hydropower has been greatly expanded, but the expansion possibilities for traditional hydropower are limited. Large investments have been made into other "renewable" alternatives, such as solar power, wind power and bioenergy for electricity production. These sectors have grown quickly in several countries, however, often with the help of relatively large subsidies. Research is underway to reduce costs. If this expansion is to continue, extensive investments will probably be required into reinforced systems for high voltage electricity supply (grids) and smart grids. This would make it possible to control consumption in order to effectively compensate for fluctuations in electricity production from variable renewable sources.

Hydropower would also likely have to be used in a different manner than today, so that it could interact better with the non-controllable production from wind and sunlight. Other areas, such as wave power, underwater current power and geothermal power, have a large technical potential if the costs can be reduced.

For stationary facilities like power plants, one possibility for continuing to burn fossil fuels or biofuels without carbon dioxide emissions is to use Carbon Capture and Storage (CCS). On the transport side of things, the development is going towards electric cars, but the use is lessened by limited range and relatively long charging times. New technical advances, primarily within battery and fuel cell technology and hydrogen gas storage, could possibly lead to quick changes in this respect. This would contribute to Sweden's vision of a fossil-free car fleet by 2030. New methods (different biochemical and thermochemical processes) are being developed to transform biomass to renewable fuels, chemicals and materials in so-called energy combines or biorefineries.

The next generation experimental fusion reactor, ITER, is being constructed, and if successful, it could make fusion power an important energy resource within a foreseeable future. The ambition is to construct a demonstration reactor (DEMO) in the 2030s, in order to then deliver energy to the electric grid prior to 2050. New generation fission power plants, such as GenIV, or accelerator-driven systems (ADS), could be important for the energy systems of the future through more effective use of nuclear fuel, higher security and less waste problems. The research reactor MYRRHA may come to contribute to this development. Nuclear research, much like other energy research, depends on experimental and demonstration facilities to develop and test new technology. There is also a need for facilities for material analysis; to understand processes in the current nuclear energy system and to develop future systems. A large number of such facilities, both in the form of experimental reactors and other facilities exist or are being constructed at the national level. As the result of a collaborative agreement with France, Swedish researchers are participating in the preparatory work on the Jules Horowitz Reactor (JHR), which is being constructed. JHR is intended to study ageing and material damage in existing light-water reactors. Swedish researchers are also participating in the ASTRID project, where a future, sodium-cooled GenIV demonstration reactor is being planned.

In many ways, the energy sector is very important to society, and at the same time it is undergoing great changes. As we do not know which types of energy and technologies will be dominant in the future, major targeted initiatives across a wide spectrum are strongly motivated. These initiati-

ves should be coordinated between the many relevant stakeholders, and at multiple levels.

Infrastructure financed by the Swedish Research Council

In addition to the research infrastructures that may be considered fully devoted to energy research, there is a line of infrastructures used both for energy-related research and other research. One example is the synchrotron light facility MAX-lab, which is used in battery research, as well as ICOS, which measures carbon dioxide fluxes to contribute to our understanding of how the use of fossil fuels may influence the climate. There are also a number of different pilot and demonstration infrastructures that have been developed partially with government support, though not from the Swedish Research Council.

ITER and EUROfusion

The experimental reactor ITER is jointly constructed by the EU, Japan, South Korea, China, India, Russia and the USA, and is expected to be completed in the south of France in the mid-2020s. The goal is to produce net energy, and thereby lead the way for tomorrow's energy-producing fusion power plants. The European deliveries to ITER are coordinated by the Fusion for Energy (F4E), in which Sweden is a member. In parallel with ITER, two experiments are also being constructed in Japan, as part of a collaboration between the EU and Japan: a superconducting tokamak (JT60-SA) and an accelerator-based facility for neutron radiation (IFMIF), which will study materials for a fusion reactor in preparation of the DEMO project.

As of 2014, the European initiatives are coordinated by the EUROfusion consortium, which includes all the EU member countries and Switzerland. In addition to its research and development relating to ITER and DEMO, the consortium also runs the fusion experiment JET. The consortium is also co-funding experimental activities at the medium-sized European fusion facilities. Through EUROfusion, Swedish fusion researchers are given new opportunities to participate in the research at these facilities and to test new concepts, which can then be scaled up for JET and ITER. EUROfusion also invests in e-infrastructure with standardised data models of physical objects, databases and tools to connect numeric codes to meta codes.

Description of potential new infrastructure

MYRRHA

MYRRHA is a planned accelerator-driven testing and demonstration reactor at SCK•CEN in Mol, Belgium. The infrastructure has been prioritised by ESFRI and focuses on fourth-generation fission reactors and transmutation of spent nuclear fuel. The purpose of MYRRHA is to test and validate technologies, nuclear fuel and material for future fission reactors in a realistic environment. In addition it may contribute to the isotope production for medical applications. MYRRHA will demonstrate the possible operation of an accelerator-driven system (ADS). ADS reactors have the potential to drastically reduce the amount of long-lived actinides in today's nuclear waste after transmutation with fast neutrons. MYRRHA is currently in the planning stage, and was evaluated by the Belgian government in 2014. The facility is estimated to be operational in 2025, at a total cost of 960 million euros. Funding is expected to come from an international consortium.

Strengths and weaknesses

The particular nature of energy research and the roles of various authorities

The Swedish Research Council is responsible for curiosity-based basic research as well as for research infrastructure matters in a wider sense, including applied research and energy research. In order to achieve politically desirable approaches to energy, the Government has established a special authority, the Swedish Energy Agency, tasked with a broad commission including research and research-related development collaboration, but with certain focus areas. The energy sector is large, and important to the country, and other government funding bodies also contribute extensive support to energy-related research. In addition, it is sometimes difficult to draw any clear boundaries between research infrastructure, testing facilities and demonstration facilities, which is significant when it comes to drawing the line between the areas of responsibility of the various agencies. Several potentially interesting research programmes are being carried out or planned at infrastructures that fulfil the general criteria set by the Swedish Research Council for support,

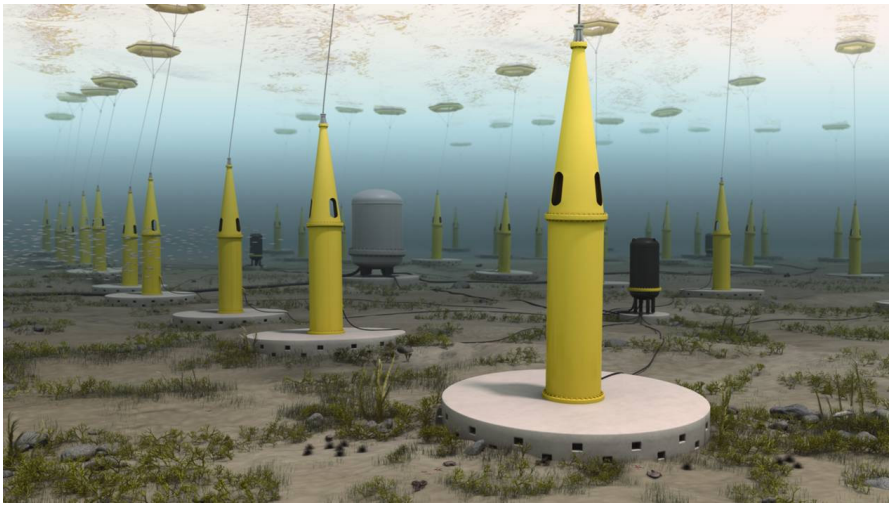
but which have not applied for such support from the Council. Many of these infrastructure programmes and investments are instead supported by the Swedish Energy Agency, among others. An increased level of collaboration between the Swedish Research Council and the Swedish Energy Agency would probably provide better conditions to achieve academic excellence within several fields. Within the area of energy efficiency, there are also strong links to the research areas of the research council Formas. It is therefore very important to have an effective coordination between the concerned authorities.

Within certain areas, Swedish energy research is part of the international front. The nature of energy research means that this often takes place through participation in large, internationally integrated projects, such as ITER. Clear political preferences and very high costs of energy-related research means that the direction of the research is to a relatively high degree guided by policy decisions. A clear example is nuclear power research, where research opportunities were limited for a long time through political control. Forceful, policy-governed decisions provide opportunities for focused initiatives, which can contribute to leading research, but at the same time, they entail long-term risks, as political decisions may change.

Development of renewable energy

In later years, extensive targeted support has been directed towards research intended to increase the possibilities of obtaining energy from wind, water and sun; primarily in the form of electricity. The same is true for research into how to extract energy from biomass, primarily in the form of fuel, heating and electricity. This has resulted in several new facilities, partially financed by the Swedish Research Council, with activities including new concepts and large-scale testing and demonstration facilities. Within a number of areas, Sweden is clearly in the international top. However, the international competition is harsh, which is why it is important for the investments made to truly deliver competitive solutions. For this reason, such investments should be continuously evaluated.

Hydropower is very important in Sweden's electrical supply, and may become even more important in the future. This is because it can be used as a balancing force for an increasing proportion of intermittent electricity production. Continued research and development of hydropower is therefore of great importance. In this respect, there is a risk of government support for basic research being too severely limited as a result of the hydropower industry being considered as well-established and having its own resources for development work.



In the borderland between engineering sciences and energy research several investments in alternative energy sources have been made, including green fuels, wind and wave power. The image shows an animation of a wave energy park. Image: Seabased.

Many of the most relevant infrastructure investments for the production of next-generation biofuels are currently testing- or demonstration-type facilities. Interesting infrastructure issues include the improvement of thermochemical and biochemical processes for production of green fuels as well as new materials and chemicals in biorefineries or energy combines. These facilities support research on biomaterials and biobased economies in the wider sense.

Important infrastructures for research on the production and harvesting of biomass raw materials include SITES (coordination of field stations), which covers long-term, forest-based field trials.

Targeted support has also been provided to research on more effective use of energy, such as smart electric grids, to improve the management of varying electricity production from renewable sources, and to develop transport systems, for example in the form of better batteries to make electric cars more competitive. Sweden's relatively strong position within relevant parts of materials science, as well as the domestic electrical engineering industry means that Sweden has several successful groups within this field. However, the development of complex systems, such as smart electric grids, requires large-scale testing, and these activities are often conducted in the form of development and/or demonstration projects.

Nuclear energy: Fission and fusion

Sweden's historically strong international position within nuclear power research (fission) has become weaker. In addition, there is no national strategy for this research, which makes coordination of the Swedish nuclear research programme more difficult. However, in 2010 Sweden entered a collaborative agreement with France, involving researchers at Swedish universities in the preparatory work for the research reactors ASTRID and Jules Horowitz, with a focus on educating young researchers and doctoral students. The ESFRI roadmap from 2010 proposes a European investment in a research facility for accelerator-based nuclear technology and the development of GenIV technology – MYRRHA. After receiving applications from Swedish research groups, the Swedish Research Council has found that there is great interest in the country for participation in the European operation, and that there is a need for national coordination. The Swedish Research Council has therefore approved the Swedish group's participation in the joint planning of the facility on behalf of Sweden.

Swedish experimental fusion research is internationally prominent, which is reflected in the country's strong position within the EUROfusion collaboration, and in the ongoing ITER contracts. This has been made possible through the European collaboration giving Swedish researchers access to international infrastructures, primarily JET. As of January 2014, this collaboration has been expanded to also include the medium-sized fusion experiments of Europe. This entails new opportunities to study the scaling of plasma and materials physics against the dimensions of a reactor, and to test new concepts (for example measuring instruments and plasma phenomenology) in smaller experiments, to later move on to testing the same concept at JET.

The contracts within EUROfusion and F4E are awarded under competition, and entail funding of around 50 per cent. In most European countries, but not in Sweden, the fusion research is predominately run by laboratories operated by national atomic energy agencies with direct funding. Many of the relevant projects are of a more technical nature, and in the Swedish system it may therefore be difficult to obtain the remaining funding for these projects.

Fossil fuels and CCS

CCS (Carbon Capture and Storage) is a technique that allows for the storage of carbon dioxide inside geological formations, on land or at sea, in order to neutralise the effects of carbon dioxide emissions from the combustion of fossil fuels. Not least the Swedish industrial and transport sectors are currently highly dependent on fossil fuels. However, the extraction of fossil fuels in the country is small, a fact that is also reflected in the research.

Despite this, Sweden plays a prominent part in a number of matters relating to this research field, above all where broader methods can be applied to the questions asked. One example is CCS, where Swedish researchers have held prominent roles in a number of projects, and have also led activities at the EU level. CCS research is to a great extent applied research, and it requires extensive research infrastructures and testing facilities. There are no major facilities in Sweden, but a number of research initiatives have been funded by the concerned stakeholders, including the Swedish Research Council, the Swedish Energy Agency, Elforsk and the EU. One question that will probably be investigated within the next few years is the use of CCS at combined power and heating plants.

The global future of Sweden

The energy sector and its associated research are developing relatively fast. The sector is responsible for a significant part of the country's GDP, and the large costs mean that cheaper solutions that are politically and environmentally acceptable will outcompete other solutions in the long term. The rapid developments within research may also come to be reflected in quick changes in terms of political direction in the shorter term. Since the energy system is to a great extent international, energy research is also guided by what goes on abroad. There are therefore great opportunities, and unless effective and realistic assessments are made of the situation, also great risks associated with targeted investment into energy research and its associated infrastructure.

Need for e-infrastructure

E-Science is becoming increasingly important within many energy research areas, such as combustion and gasification, as well as fusion and nuclear engineering. Within fusion and nuclear engineering research, simulation and modelling constitute very important components. This means that e-infrastructure with standardised data models of physical objects, databases and tools to connect numeric codes to meta codes are becoming increasingly important. Fusion research in particular requires high-performance data resources for modelling, primarily of fusion plasmas and measuring equipment, and to optimise the design of components for ITER and DEMO. These resources are needed both nationally, via SNIC, and internationally via PRACE. There is also a need for application experts to develop, maintain and optimise simulation codes as well as infrastructure for the development of integrated meta codes.

Trends and tendencies

Energy-related research, especially if it receives targeted support, is often need-driven. The development of research and associated infrastructures is therefore relatively strongly guided by opinions of future needs, assessments of technical possibilities and political orientation. The international development will have a strong impact on Sweden, even if the country's energy sector is different from that of most other countries as the result of a nearly fossil-free electricity production and a large use of biomass. Examples of large changes that could be made is the use of large-scale European shale gas production or the extraction of geothermal energy with the use of modern drilling and hydraulic fracturing methods – areas in which large projects are currently underway, for example in Switzerland. The politicians must pave the way, but as future orientations must take technical capacity and scientific analysis into consideration, the decision-makers must be provided with the best possible scientific information.

Over the coming period, there will probably be a strong European and global development within several important areas; in both renewable energy for the production of electricity and fuels (biofuel and solar, wind, hydro- and wave power) and fission power. Potential progress within the integration of intermittent renewable electricity within the grid, CCS, climate research, shale gas production, electric vehicles, energy efficient transport, society and industry as well as energy system research must also be considered.

Such development will have a great impact on the levels of carbon dioxide emissions and the economies of various countries. Within several fields, the infrastructure needs are characterised by the access to facilities like MAX IV and/or demonstration facilities that do not fall within the area of responsibility of the Swedish Research Council. Since different components of the energy system are part of a complex interaction, and society wishes to see new, practical solutions to the energy problems, a more effective collaboration between various research areas and stakeholders is desirable.

Fusion research is currently going through a transformation, with reduced funding for basic research and with an internationally coordinated and integrated programme for research and technology development for ITER and the planned demonstration power plant DEMO. This means that at several European fusion facilities, attempts are made to place more emphasis on technological development (wall materials, wall geometry, fuel cycle, heating systems etc.). The increase in coordination and integration also means that researchers have to take on a larger part of the organisational and administrative work of defining and coordinating research and technology development within the European collaboration. This applies not least to Swedish researchers, who are well-represented as subproject leaders within the EUROfusion consortium.

Nuclear research is currently focused partly on developing technology for fourth-generation fission reactors, and partly on extending the lifespan of existing reactors. The problem of waste is still a current one, with hopes of minimising and/or transmuting long-lived waste in future reactors, or storing it geologically in a safe and permanent manner. Several solutions are studied, and the construction or planning of testing and demonstration facilities is underway.

Recommendations 2015–2020

Energy systems, natural resources, climate and environment

Since society's choice of future energy solutions will be governed by the supply of natural resources and the environmental strains that the use of such resources will entail, it is important to have suitable research support and relevant infrastructures that can be used effectively to obtain knowledge on the consequences of various options. Important research infrastructures include SITES (coordination of field stations), ICOS (carbon dioxide observation system), the EPOS systems for geological and geophysical observation data, the research ship Oden, and the Riksriggen infrastructure for deep core drilling. E-infrastructures of various sorts will most likely become more important. E-infrastructure includes databases for everything from climate data and the behaviour of electricity consumers to information about forest stands. Several energy research areas require a very large computation capacity for modelling etc. E-infrastructures with relevance to energy should also be planned based on the needs of energy research.

Renewable energy

Research on renewable energy needs access to advanced infrastructures within several research fields, such as the infrastructures Myfab and MAX IV within materials research. This need refers to research on renewable electricity and fuel production, the development of smart grids to cope better with varying electricity production from renewable sources and increased use of biomass. It is important to consider the needs of energy research when relevant infrastructures are being planned and constructed.

The planning of new research-related pilot and demonstration facilities that are mainly financed by government agencies should be conducted in consultation between these agencies to ensure that the national system as a

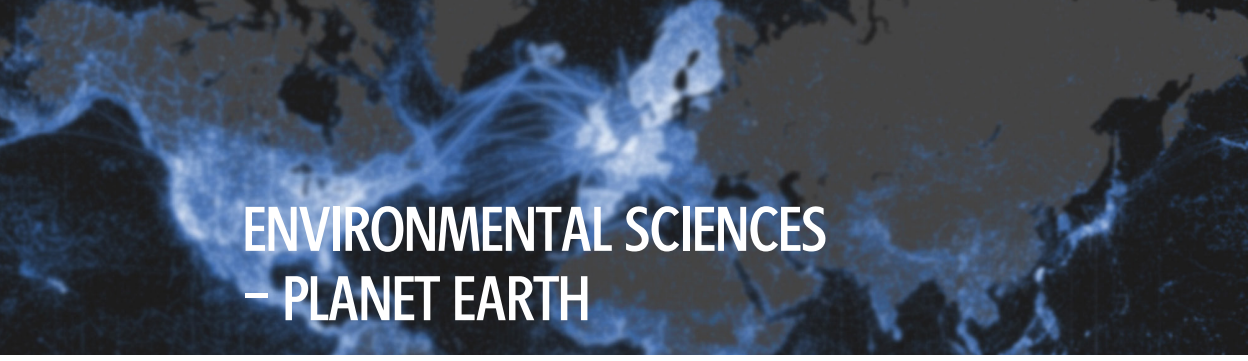
whole is interconnected in a reasonable way. In certain cases, infrastructure support may be required for new prototype facilities within the area, and it should be possible to apply for funding for this from the Swedish Research Council or another government agency. Targeted calls relating to such infrastructure may be motivated.

Fusion research

In order to maintain a competitive Swedish fusion research, Swedish researchers must be able to contribute to both research and technology development within the coordinated European fusion programme, through membership in the EUROfusion consortium. Within the consortium, the Swedish contributions go to the JET experiment, and to the supplementary facilities MAST, ASDEX-Upgrade, TCV and Wendelstein 7-X. EUROfusion is also coordinating the design of a demonstration reactor, DEMO, which is intended to start supplying electric energy before 2050, and the development of a European e-infrastructure for integrated modelling and data analysis, for which Sweden contributes application experts. Swedish researchers have an opportunity to contribute to the development of ITER, but both EUROfusion and ITER (F4E) require extensive in-kind contributions. Such funding may be difficult to obtain in Sweden when the projects are of a technical nature, and provide no direct academic results. It is important to find suitable funding possibilities to enable Swedish researchers to participate in these infrastructure projects. The situation is made more difficult by the fact that funding for the JET Joint Fund, which was paid by the Swedish Research Council during the Seventh Framework Programme, will be eliminated. This will lead to an increase in the cost of participating in JET

Nuclear research

Particularly in consideration of the climate issue, it is important for society to have the technology required in choosing to build new, safer and more effective nuclear reactors. This requires Swedish researchers to be actively involved in international collaborations, to gain access to infrastructures abroad. The involvement in the French facilities JHR and, in the long term, ASTRID should be given the chance to continue. A future Swedish participation in the ESFRI project MYRRHA may also be considered, as that facility will have a very broad and relevant research profile, with the aim of developing future reactor types.



ENVIRONMENTAL SCIENCES – PLANET EARTH

Description of the field

Some of humanity's greatest challenges lie within the environmental sciences. This includes basic research and applied research fields spanning from natural resources and food production to climate change and natural disasters. Large and long-term research infrastructures are needed to cover the many interacting systems inside, on and above the surface of the earth. These involve ecology, including ecosystem studies on land and at sea, atmosphere, hydrosphere and ionosphere research, geology and geophysics. The research stretches from basic research to understand the myriads of interacting processes that make nature what it is, to applied research regarding the interaction between humans and our environment, today and in the future.

A globally growing population with increasing demands on living standards puts a lot of strain on earth's resources. Safeguarding welfare, environment and natural resources therefore requires an increased understanding within many of the research areas that relate to planet earth. A sustainable society requires building and planning processes to be developed in consideration of the environment, and for the consequences of climate change to be analysed. Our lifestyle is leading to increased consumption of water, energy, raw materials and food, which requires new and more effective methods of finding and using the earth's resources. Competing interests from forestry and agriculture, tourism, room for cities and factories, and the mining, energy, fishing, and water industries etc. are placing increasingly high demands on effective technologies to monitor, map and investigate the earth's biological, chemical and physical assets. Increased use of resources often leads to an increased environmental impact, as new problems arise while existing problems are made worse. In later years, particular emphasis has been placed on carbon dioxide emissions from fossil fuel combustion in relation to the climate, the use of natural resources and pollution problems, product development and new chemicals, as well as matters relating to the loss of habitats, biodiversity and ecosystem services. More detailed research within – and in the intersecting areas between – different fields such as earth sciences, ecology, atmosphere, environment, spatial planning and social sciences is required to understand and manage the challenges of today and tomorrow. In order to

achieve this, a number of long-term research infrastructures of very different character are needed.

Relevant to the field are infrastructures of various kinds: laboratory facilities (such as VEGA for laser ablation mass spectrometry), distributed observation activities (such as ICOS, SITES and EPOS), facilities (such as the Onsala Space Observatory, ESS and MAX IV), expensive mobile resources (such as Riksriggen for deep core drilling) as well as e-infrastructures of different types (such as ECDS). Some of the infrastructures are national, others international. In some cases, the Swedish Research Council is the main funder. In other cases, such as IODP-ECORD, the Swedish Research Council makes a contribution to an internationally owned and operated infrastructure. Planet earth is studied using all kinds of tools, for example within biology, chemistry, physics and earth sciences. This area is also strongly connected to archaeology and palaeontology. As the time scale of observations is governed by natural processes, which may be very long, a number of activities require observations over a very long period of time, sometimes hundreds of years.

There is often a clear interface with other agencies' areas of responsibility, for example in terms of environmental monitoring and the use of natural resources. In addition, newly started infrastructures, which were initially motivated by research needs, may be used for other important government activities after a while. In some cases, there should be a dialogue between the Swedish Research Council and other stakeholders regarding the responsibility for specific infrastructures, where the involvement of the Swedish Research Council may be developed or withdrawn over time, even if the actual infrastructure remains.

Research areas and associated infrastructures may be classified in different ways. A few, partly overlapping, groups with relevant existing areas are listed below, followed by a more detailed description of a selection of the most important research infrastructures. The list below includes a few ESFRI projects that are in the planning phase. For many of these infrastructures, it is impossible to calculate the number of "users", primarily as they collect or provide data over long periods of time, and because their data is openly accessible for download over the internet. In addition, many relevant research questions are of a global nature, and much data is delivered to joint integrated international databases, which makes it difficult or even impossible to monitor the use of data that is specifically Swedish.

Infrastructure financed by the Swedish Research Council

Buoy-based environmental measuring system

Climate changes also affect the physics, chemistry and biology of the water. One collaboration between five research institutions/higher education institutions consists of a distributed buoy-based environmental measuring system placed in a number of key positions along the Swedish coast. The buoys continuously measure physical, chemical and biological parameters at varying depths, to study the mechanisms of eutrophication, acidification and other changes to the unique environment of the Baltic Sea, both short-term and long-term.

Sampling from boat at the Erken Laboratory, which is one of nine field research stations within SITES, a national coordinated infrastructure for terrestrial and limnological field research. The other field research stations are Abisko, Tarfala, Svartberget, Röbäcksdalen, Grimsö, Asa, Skogaryd and Lönnstorp. Image: Pia Larsson, Erken Laboratory.

EISCAT (EISCAT 3D)

Sweden hosts the international organisation EISCAT Scientific Association, which is based in Kiruna. The facility was developed for research on the aurora borealis, as well as plasma and atmospheric physics, but is also used for research on meteorites, space safety and radio astronomy. By using a radar system with a powerful transmitter in combination with very sensitive receptors in three locations in Arctic Scandinavia, EISCAT is the only research facility able to provide full vector information on phenomena in the atmosphere and near space. The existing EISCAT radar system in northern Scandinavia and Finland will be phased out within a few years, when the frequency rights are taken over by commercial stakeholders. As its replacement, the EISCAT 3D project is at the threshold between the planning and implementation phases. EISCAT 3D is based on the same fundamental principles as EISCAT and will provide the same possibilities, but with a spatial and temporal resolution which is several times higher, while going from a sweeping line through space to making simultaneous observations of great volumes. At this critical stage, the Swedish Research Council is supporting the head office of the facility with grants for planning and international coordination. At least five countries in the EISCAT Council, including Sweden, are expected to make a funding decision in the autumn 2014 for the construction of EISCAT 3D.

ICOS

The ICOS (Integrated Carbon Observatory System) initiative, originally initiated by ESFRI, is a pan-European network for measuring and quantifying greenhouse gas uptake and emissions between land/water and the atmosphere. An ERIC is currently being formed to govern the activities. Sweden is also the host of the European portal function that is to store and deliver research data. Within the framework of ICOS, the Swedish Research Council is funding a number of activities relating to carbon dioxide flux measurements on land and at sea. These activities consist of three high masts (100–150 meters high) for atmospheric measurements, as well as seven ecosystems across the country. A marine station will be added to these, at Östergarnsholm, which will also offer studies of gas exchanges with the sea. These processes can also be studied with the help of a mobile measuring system mounted on the icebreaker Oden. These types of supplementary exchange measurements are also available at the land-based ICOS stations, to provide information on the interaction between the atmosphere, the ground and vegetation, and in some cases, the outflowing water.

The purpose of ICOS is partly to understand the local varieties of carbon exchanges, and partly to facilitate the quantification of greenhouse gas ex-

changes across Europe. The ICOS data is thus important for many researchers from an international perspective.

GET

Through the distribution service GET, geodata from the National Land Survey of Sweden, the Swedish Transport Administration, Statistics Sweden and the Swedish Maritime Administration is provided free of charge for use within education, research and cultural activities. To gain access to this geodata, a licence agreement must be signed. For higher education institutions it is possible to use the distribution service GET to download part of the data that the agreement provides access to. The service also gives access to data from the Geological Survey of Sweden.

Environmental and climate databases

There are currently a number of different databases for different sorts of environmental and climate-related data. ECDS at SMHI is primarily a meta database for researchers to obtain information on which environment and climate data is available, and how they can access it. LifeWatch and GBIF, with the Swedish University of Agricultural Sciences (SLU) and the Swedish Museum of Natural History (NRM) as their respective principals, are databases for biodiversity informatics. The WRAM database (SLU-Umeå) is a related database focused on processing and making available data on animal movements. Sweden (Lund University) has taken on the responsibility of running the ICOS portal, i.e., the database function to make data and analysis tools available. The Swedish National Infrastructure for Computing (SNIC) can be used by researchers from all disciplines. Data that is relevant to climate research is also collected by satellites, and a function to secure both data and access to it is being administered by Chalmers (Resdacs, database of earth observations for climate research).

Nordsim and VEGA

The new VEGA centre, which starts in 2014 at the Swedish Museum of Natural History, uses laser technology to detach material from geological samples, which can then be analysed with the help of a mass spectrometer. The technology is capable, for example, of selecting samples with great precision from different parts of a rock crystal, which provides important information on how different crystals have been formed and influenced during different geological eras. This activity is governed by a national steering group. The

Nordic instrument Nordsim is similar, but the material is instead detached by an ionic beam. Planning of instrument time slots is conducted by a Nordic committee appointed by the Swedish Museum of Natural History in consultation with the Swedish Research Council.

Riksriggen – scientific drilling

Riksriggen is a drilling rig for scientific investigations of the earth's crust, down to a depth of 2.5 kilometres. It is managed by Lund University. Certain supplementary equipment and activities associated with the drilling rig are found at other universities, such as the equipment for downhole tension measurements (Luleå University of Technology). Important research questions that can be studied using deep core drilling include the geological development of the bedrock, life deep in the mountain, large-scale ground water systems and calibration of climate models through temperature measurements.

In addition to basic research, the rig can be used for applied projects, such as studies of the possibilities for geothermal energy extraction and mountain storage of carbon dioxide. Before deeper drilling, extensive preparatory studies are required, primarily of the geophysical conditions for optimal placement of the borehole and planning the actual drilling as well as the scientific work at the drill site. Sweden is participating in two large international scientific consortiums for drilling: the deep sea drilling programme IODP, through its European branch ECORD, and the ICDP, which is the land-based equivalent.

SITES

The Swedish Infrastructure for Ecosystem Science (SITES) is a newly established, distributed research infrastructure which coordinates a number (presently nine) of Sweden's field stations for land-based climate, environment and ecosystem research. The purpose of SITES is to offer researchers at all the country's higher education institutions and research institutes well-functioning and generally available infrastructures for field-based research. Together, the stations cover widely different nature types and climate zones, from agricultural landscapes, forests, mountain areas and wetlands to various types of inland waters. The actual core activities at the stations are funded by the various principals SLU (Svartberget, Grimsö, Asa, Lönnstorp and Röbäcksdalen), Stockholm (Tarfala), Uppsala (Erken) and the University of Gothenburg (Skogaryd) as well as the Swedish Polar Research Secretariat (Abisko).

Strengths and weaknesses

The research in environmental sciences is broad, spanning many different research fields, and in many cases it requires international coordination. The impact varies between research fields, but overall, the Swedish research is of the highest international class. There are several well-established infrastructures in Sweden, and important e-infrastructures were developed here at an early stage. Thanks to this, Sweden is at the forefront of certain areas. Ecological research, such as the study of terrestrial, limnic and marine ecosystems, ecosystem services and biodiversity, is a traditionally strong area in Sweden, partly due to earlier targeted research initiatives. Climate and atmosphere research is another strength. The proximity to the polar region (where many important processes in the ionosphere take place) means that space research has long been a profile area. Despite the fact that Sweden's natural resources, including the forest, agriculture, seas and mining industry, have been enormously important to the country's economy, the proportion of researchers involved in geology and geophysics, or associated infrastructures, is not as great as in many other comparable countries. Even so, Sweden is considered to be at the international forefront of a number of relevant research fields.

Sweden is a large country with a relatively small population. For this reason, proportionately speaking, more resources are needed to cover the country (including the water) with measuring points for empiric studies than in many other European countries.

Long-term funding

In part, the infrastructures are similar to those within other research fields. One example is laboratory activities such as mass spectrometry and different database functions. However, there is also an extensive need for other types of infrastructures to study the earth. These include large mobile facilities, distributed observation systems and large collections of biological and geological material. It is highly beneficial for Swedish research to have access to mobile facilities, like the icebreaker Oden, and the Riksriggen infrastructure for deep core drilling. A common concern for these and similar facilities, however, is that the planning and operational costs may be great, and there is no natural address for such costs within the research-funding system. These costs may be considered "project costs" instead of infrastructure costs, but they are of such a nature, and may be so extensive, that they do not fit within the framework of a regular project research grant.

Observation activities may come in many different forms. Some are geographically distributed, where different components can have different principals. This can be a strength, because the costs are shared, as well as a weakness, as it can make coordination more difficult. In the cases where one principal takes full responsibility, long-term funding may be a problem. Effective coordination and a clear division of responsibilities between different principals, as well as between the principals and the Swedish Research Council, is needed to achieve stability in the long-term time scale that is often required for the infrastructure to have an impact.

Marine research

Marine research requires appropriate infrastructures of several kinds, not least access to suitable ships, including large seagoing research vessels. Research ships are important from the perspectives of several disciplines; from geology to climate, ecology, fishery and so on. They can be dedicated research ships, but most often they are also used for other purposes, like the exercise of public authority, monitoring the environment and education. There are a number of such ships, with various principals, spread around the country.

As the successor of EISCAT, the ESFRI project EISCAT 3D, the world's most advanced research radar, is at the threshold between planning and implementation phase. Image Copyright 2009, EISCAT Scientific Association.

Since the capital and operational costs are great, effective national coordination is required. Unfortunately, the current trend is to suboptimise the use of these ships, so that single stakeholders acquire their own ships, which entails a risk of making them comparatively expensive to operate. This also applies to other forms of marine research resources, which are suitable for use as common infrastructures. Similar problems can also be seen when it comes to other types of research stations, mass spectrometers and other costly specialist instruments. A better collaboration between higher education institutions, authorities and institutes is needed.

Environmental research

Sweden has unique data that describe the situation in the country's forests over the last century. Generally speaking, environmental, biodiversity and ecosystem research has undergone something of a revolution lately, due to new technical advances. One example is database functions such as GBIF, SLW, ECDS, RINFI and WRAM, the intensive local environmental measurements that are conducted close to the ICOS carbon dioxide flux stations, and an increasing number of different observations on land and at sea. However, certain infrastructures for data production and management, and for analysis within toxicology and environmental pollution, are lacking.

Climate research

Sweden has long made significant contributions to the development in this area. Today, there are a number of important infrastructures related to climate issues. One such example is ICOS, where Sweden is operating a number of measuring stations, and the "portal function", i.e. the e-infrastructure where researchers are to be provided with effective access to data and analysis tools. These climate-related infrastructures focus on processes relating to greenhouse gases. Important open questions within climatology relate to aerosol particles and clouds, where other types of measurements are relevant, and the observational infrastructures are not as well developed. Studies of the atmosphere are of course central within climate research, but the interaction between the atmosphere and the near-surface ground, vegetation, hydrosphere and cryosphere, including lakes, oceans and glaciers. Studies of the deeper soil are also relevant from a climate perspective. Sweden is involved in extensive research activities within quaternary geology based on the climate archives stored in ice and sediment cores.

In addition to the observational systems and databases, climate models are essential to understanding the climate system and its development on

different time scales. Climate models constitute a prominent research field in Sweden today, but a critical factor is continued access to extensive and increasing computation capacity.

The research needs are extensive, and a clearer prioritisation is required when it comes to infrastructures within this field. Examples of such infrastructures are SITES (climate data research stations), ANAEE (analysis and experiments in ecosystems) and ACTRIS (climate and aerosol measurements).

Space research

Infrastructure for space research is supported in part by the Swedish Research Council, and in part by other stakeholders like the Swedish National Space Board (the Odin satellite, Esrange, contributions to the activities of the European Space Agency [ESA] etc.). However, the scientific production from important parts of the Swedish space research community has gone down in recent years. EISCAT-3D is a large-scale facility currently in the planning phase, which will be used to study the ionosphere and the atmosphere with the help of radar waves. The project is scientifically well-founded, but costly. A number of questions relating to the division of responsibility between the various stakeholders involved, not least from Sweden, Norway, Finland, Japan and England, need to be answered before the project can start.

Polar research

Sweden's traditionally prominent role within research at and about the Arctic and Antarctica continues, not least because of the access to the icebreaker Oden, the subarctic research station Abisko and the glacier research station Tarfala, of which the latter two are part of SITES. As with many projects in the Arctic, the possibilities are strongly associated with active support from a number of countries. The ESFRI projects SIOS (Svalbard Integrated Observing System) and EISCAT 3D are being planned.

Solid earth

In later years, the Swedish Research Council has supported a number of drilling projects. These include the deep sea drilling programme IODP and the European component ECORD, land drilling in the form of Riksriggen and operational support to a first deep core drilling outside of Åre. Sweden also participates in the planning phase of the ESFRI project EPOS (European Plate Observing System), which focuses on natural disasters and natural

resources, and which in many ways is Europe's largest ongoing earth science project.

There are also leading activities for advanced mineralogy analyses at the Swedish Museum of Natural History, which supplements a number of instruments at different universities. It is important to increase the national coordination of these infrastructures.

Career opportunities

Relevant research fields and their associated infrastructure are very different, and the situation for young researchers therefore varies greatly within different disciplines. There is already a lack of staff with expert skills within certain areas. There may be a risk that talented young researchers move abroad if they feel that there is no stable and long-term funding within their own discipline, and for the type of infrastructure they need. Since an increasing focus is being placed on individual performance in the form of publications and citations, their involvement in infrastructures may come to have a large impact on their career. Working on operating an infrastructure and helping other researchers does not automatically lead to qualifications, despite advanced measures being necessary to ensure the development of research at the infrastructure. A dialogue should be held with the universities and a clarification made when it comes to the evaluation of research applications, that the assessment of a researcher's performance should take more than just publications into consideration, not least when it comes to infrastructure involvement.

Need for e-infrastructure

The complexity of the world around us, combined with an increasing research focus on environment, climate and natural resource issues, entails a significant increase in the amount of different types of data as well as great needs for computer-based modelling. The need for computation capacity increases rapidly along with the development of complex modelling tools, such as climate models that better describe integrated systems with the atmosphere, oceans, ice and biosphere. In this regard, SNIC plays a central part. A number of databases, with extensive observational data and associated analysis tools, already exist, and a number of broader initiatives, such as SITES, have e-Science components. Many modelling tools, databases and functions are new and under development, while others are at the planning phase. Further development and tools are needed to guarantee effective access to data, often for a long time to come. More effective coordination bet-

ween various existing and upcoming databases will be necessary, and should be possible to develop, not least within life sciences, earth sciences, environmental sciences and materials science.

Trends and tendencies

Increased international interest

Internationally speaking, research on the earth and nature is drawing increasing attention, not least due to the enormous challenges that modern societies are faced with. To give an example, three of the five current major projects of the European Institute of Innovation and Technology (EIT) clearly relate to this area ("Climate", "Energy" and "Raw Materials"). More than one third of ESFRI's planning-phase projects are furthermore listed in the current roadmap as linked to the environmental sciences. These areas are also well-represented in the current European research programme Horizon 2020, including the parts focusing on research infrastructures. This development is due to the research questions being current, new measuring methods being developed and the fact that certain research infrastructures have not been kept up to date.

As shown by the large number of ESFRI projects, there is an increased need for international coordination; partly for streamlining purposes (for example in respect of method development), partly because of the need for geographic coverage, and partly because the costs of some functions can become unreasonable for an individual country. As several of the relevant activities relate to the very long term, stable funding is of the utmost importance. It is also important to synchronise the Swedish strategy with the European one, to secure long-term funding, and to make national infrastructures available to foreign users.

Collection and integration of large amounts of data

Many relevant research questions cannot be broken down into smaller subquestions. Instead, larger sets of complex problems must be analysed as a whole. With many different measuring points, high temporal resolution, high precision and longer time series, unique data is created to understand processes in, and between, different systems, for example between climate and ecosystem. It has therefore become more common to use increasingly

sophisticated field research infrastructures and computer models of large and complex systems, even within areas where computer modelling has not previously been an established practice. A strong trend in research-intensive countries like the USA is that an ever greater focus is placed on constructing super sites, which are often supplemented with geographical data spanning the whole country.

A technology that has long been advancing within several disciplines is autonomous stations, vessels and robots, which can act independently and take measurements over long periods of time in locations that are too dangerous or simply too expensive to man. This is particularly relevant in marine research as initiatives within this field usually require massive resources in the form of ships or some other form of observational platform. There are tendencies for more and more environmentally relevant parameters being routinely monitored through partially autonomous carriers of measuring systems, and this creates more data for the research community. Just as in many other data-intensive disciplines, increased use will be based on advanced but relevant data processing and database management.

In the same way that large advancements have been made within physics by gathering forces in large infrastructures, research on the planet earth should take the same route to better understand the great challenges facing us, not least in terms of climate, environment and the use of natural resources. However, this development must go hand in hand with the development of complex data models, large databases and associated tools.

Development in Sweden

For a long time, studies of ecosystems and biodiversity have been focus areas of research in Sweden, including the associated infrastructures. However, in later years, energy matters and the interaction between nature and energy extraction and consumption have been getting more attention. There is every indication that this interest will continue and probably increase. These areas are strongly linked to climate research where a number of large investments have been made relatively recently. The development of recent years has been a reminder of how central issues relating to natural resources and energy are to the development of Sweden and Europe, and the increased research will entail a need to create new infrastructures and reinforce existing ones. Aquatic research, on both freshwater and saltwater, remains important. The future of Sweden's role within research on the upper atmosphere/ionosphere and climate-relevant interaction between the sun and the earth will be highly influenced by whether EISCAT 3D is established or not.

The opportunities for Swedish researchers to be at the international forefront, and contribute to solutions when it comes to important problems for society, depend greatly on their access to necessary infrastructure. A continuation of the currently positive trend requires the reinforcement of a number of areas. As society is making increasing demands on "utility" and deliveries from the research sector, there is a clear tendency, not least in the earth-environment field, for the research focus to be shifted from monitoring and basic understanding of the world around us to problem-solving and applications. This affects the need for infrastructure, and will probably continue to do so in the future.

Increased access to geospatial information provision for planning and decisions

Sustainable social planning requires complex knowledge integration of different subject areas and actors with different perspectives. In order to make balanced decisions, it must be possible to effectively implement and use the knowledge provided by the available information and underlying data, in both private and public activities. New knowledge can be developed through interdisciplinary projects, where engineering and social sciences collaborate, for example within systems science, organisational research, structural engineering and spatial planning.

Geodata refers to all information with a spatial component, and is a necessary part of the information supply for spatial planning, but also for research on climate and environment, agriculture and forestry, as well as natural resources and energy systems. The amount of available data sources is constantly growing, much thanks to the more open data policies of the public authorities. Swedish authorities collaborate within the Swedish Geodata Portal[15], as part of the implementation of the INSPIRE Directive[16]. Swedish research institutions have recently gained free access to the data of the National Land Survey of Sweden[17]. In addition to the collection of data from research and authorities, a new source of data has been added: Volunteers Geographic Information (VGI). This consists of observations reported by the public, one example being Artportalen (the Species Observation System)[18]. The development of information services for earth sciences opens up new and exciting possibilities, but may also entail large costs. Purposeful planning,

15 http://www.geodata.se/
16 http://inspire.jrc.ec.europa.eu/
17 http://alturl.com/qsntw
18 http://www.artportalen.se/

including collaboration between concerned government agencies, is important in terms of cost efficiency.

Recommendations 2015–2020

Balance and priorities need to be adjusted for future needs

Several factors mean that the need for support for existing and new infrastructures is great, and under development:

- The public focus on issues relating to the earth and how we live and impact on it is growing. Energy, natural resources, climate and ecosystem services are just a few of several relevant issues.

- Several areas concerning planet earth have recently been prioritised by Sweden and the EU.

- There are several areas where Swedish researchers are maintaining a high international class, but where a lack of necessary infrastructure may pose a long-term threat.

- Several relevant research fields are strongly developing at the moment, which entails new infrastructure needs.

- Longevity must be ensured for a number of observational and time-series-based research fields.

- Globally speaking, basic research within the relevant areas has increased markedly, but not in Sweden.

The above means that earlier prioritisations between infrastructures and areas may have to be reviewed in order to be adjusted to the needs of tomorrow. This applies within the area "planet earth", but also in the interaction between this and other areas. The current development means a risk of decreased access to infrastructure resources to study the earth and nature, despite a growing need.

Increased coordination of infrastructure to study ecosystems

It is important that e-infrastructure relating to ecosystems, such as GBIF, LifeWatch and WRAM are effectively coordinated. The present focus on the connection between climate and ecosystems means that effective collaboration with ECDS is also necessary. A focus on new links to research within spatial planning should be developed. The common structure for climate research and environmental research, SITES, may come to play an important role in the coordinated management of relevant long time series. This is an important investment that should be continued, with an ambition to constitute infrastructural support for all relevant research. The possible coordination of marine infrastructure for marine research, such as EMBRC, should be investigated. ESFRI projects like ANAEE, EMSO, EMBRC, LifeWatch etc. are well-motivated, and grants for Swedish participation will most likely be applied for. More large-scale coordination, and a potential combination of old and new infrastructures should also be considered, to achieve maximum benefit.

Climate research and meteorology

A decisive success factor within this area is knowledge about the connection between various parts of the climate system. This entails a complexity that requires a holistic approach in the research activities, with high-performance computer models and monitoring activities. It also includes coordination and prioritisations between various forms of measurements.

Space physics

EISCAT 3D should be supported, including active support to the ongoing international consortium formation. Long-term support requires the other involved parties to also contribute a suitable degree of funding.

Solid earth

Important ongoing activities include EPOS, ICDP/SSDP, IODP/ECORD, SIOS, Nordsim, VEGA, Riksriggen, SNSN and relevant activities conducted at the Onsala Space Observatory. Support for the drilling projects should also continue. It is important for the activities, including preliminary studies in the field and planning phases of new projects, function satisfactorily. A holistic approach within this area would be desirable. EPOS is considered an interesting option for Sweden, not least in respect of natural resources,

and Sweden should participate as long as the conditions are reasonable. At the same time, long-term support for the included observational and analytical activities within geophysics, geodesy and geology should be ensured. National and Nordic coordination of access to infrastructures for advanced mineralogical analysis, such as Nordsim, is desirable and requires stable, long-term and suitable financing models. When it comes to centralised analytical activities like VEGA, it is important to use a suitable holistic model, including direct funding and appropriate user fees, and mechanisms to prevent practical matters, such as travel expenses, from geographically limiting the use. The latter could possibly be handled through funding via the infrastructure itself, or actively considering the matter when processing applications for project research grants.

Fields relating to environmental sciences

It is not unusual for research infrastructures used within the environmental sciences to also be used for research within other fields. One example of a neighbouring field is archaeology, where a significant increase in the use of new high-technology tools offers plenty of new possibilities. Infrastructures that offer these types of tools include facilities working on method and instrument development for new applications. It is desirable to find effective mechanisms to ensure that archaeology and other areas linked to the environmental sciences get continued access to new and useful tools for their research. Another example is construction and planning processes, where the use of building information modelling (BIM) can benefit greatly from the development of new infrastructures and instruments.

Field stations

There is already a coordination body for the land-based field research stations for environmental and climate studies supported by the Swedish Research Council (SITES). To a certain extent, there are climate stations combined with these activities. SITES, along with ICOS and the concerned universities, should consider the inclusion of other possible new field infrastructures within the framework of ACTRIS and ANAEE. Other types of stations, for example for marine studies and solid earth measuring stations (such as seismic, geodetic and magnetic stations) should rather be integrated with other measuring stations within Sweden, and with European networks like EPOS. Sweden should participate in SIOS if this organisational format is appropriate and the cost is proportionate to the contributions to Swedish research.

E-infrastructure

Environmental, climate and ecosystem data should be integrated within a coordinated concept, which could mean that certain activities should be integrated. It is important to have a clear and long-term division of responsibilities between the involved stakeholders. There is a need for extensive computation and storage capacity within several research fields that are related to the environmental sciences, and in this case SNIC should be utilised. Application areas include meteorology, climate research and solid earth studies, and to an increasing degree other fields as well, in which computation-demanding models are used. It is therefore important that large-scale data and computation resources are dimensioned and designed in a way that benefit all the researchers involved.

Infrastructure for marine research

An evaluation of the possibilities for a new research and investigation ship has recently been conducted by SLU and SMHI on commission from the Government. The University of Gothenburg and Stockholm University are both investing in new ships. The Geological Survey of Sweden's (SGU) research ship is in need of renovation or replacement. In addition, there are ships at the universities of Umeå, Kalmar, Lund and others. The Swedish Navy, the Swedish Coast Guard and the Swedish Transport Agency also have ships that may be suitable for certain research purposes. Some measurements can furthermore be taken from ships that travel for other purposes. The potential for coordination gains is evident. Earlier investigations[19] have failed to solve this problem. A clear and coordinated national system needs to be developed in order for these resources to fulfil the Swedish Research Council's criteria for infrastructures of national interest. Sweden should consider participation in the European infrastructure EMBRC.

19 Official comment from the Swedish Research Council of 26/04/2010, Förslag till organisation avseende statens forsknings- och undersökningsfartyg (Proposed organisation regarding government research and investigation vessels) (Ref: N2010/9194/TE); Official comment from the Swedish Research Council 22/04/2014, Rapport God Havsmiljö 2020 Del 3 Övervakningsprogram (Report Marine Environment 2020 Part 3 Monitoring programmes).

HUMANITY, CULTURE AND SOCIETY

Description of the field

In later years, research within humanities, medicine and social sciences has become increasingly dependent on research infrastructures. Increased coordination of existing infrastructures, altered legal circumstances, cross-disciplinary collaboration, innovative infrastructures and use of improved e-infrastructure can be expected to result in significant advances in future research.

Infrastructures within the social sciences consist partly of authorities´ and the health service´s registers of individual, socio-demographic life spans, and partly of similar individual data collected through large-scale interview surveys that also include data regarding more subjective life factors. In many cases, the individual data is linked to databases that provide information on what context the individual is living in. Infrastructure initiatives should facilitate a systematic analysis of this type of individual data and social information on different levels (locally, nationally, in Europe and globally). This is to increase the knowledge of the effects of different social institutions, reforms and interventions.

In health-related databases (medicine, public health sciences, epidemiology), the collection of data is conducted through a mix of methods, such as surveys, interviews, psychological tests, physical measurements and analyses of biological samples. In several cases, data gathered by researchers is supplemented with data from records or registers with the National Board of Health and Welfare and Statistics Sweden (SCB). The value of data is refined over time through follow-up or new register feedback, and thus creates living databases. Databases that relate to medical or epidemiological questions are often of great value to several disciplines, and can be used for more detailed studies within other fields, such as psychology and other social sciences, which analyse the effects of socioeconomic and other structural factors.

The field of humanities offer several examples of research that transcends disciplinary boundaries. Archaeologists have been able to benefit greatly from achievements within the natural sciences through the archaeological research laboratories, such as the infrastructure SEAD, which provides environmental archaeology and quaternary geology data. In this context, infrastructures appear to be a strategic component.

The language infrastructure CLARIN is used for in-depth language analysis

for all disciplines that utilise language material (such as history, law and comparative literature studies). Historically oriented demographics is another area that offers examples of fruitful collaborations between historians and social scientists. By building awareness of the benefits of digitally accessible materials, both quality and comparability within historical, cultural and comparative literature studies can be increased. Digital humanities have stimulated the methodological developments at a general level, and have entailed the possibility of combining qualitative and quantitative studies. The development of digital tools and data is also important for the field of educational sciences.

There are tools for coordinating databases, but professional database management is still required for research to benefit from them. The multidisciplinary potential needs to be integrated already in the construction phase of new databases, but should also be promoted in existing databases. The benefit of interdisciplinary infrastructure can be exemplified based on questions regarding the ageing society, in which individual factors as well as contextual relationships influence the health of the elderly. In order to understand differences between countries and populations, a broad spectrum of individual and contextual data is therefore required, for example relating to the organisation of labour, health services and elderly care. As a result, infrastructures are also required that span across the medical field to the social sciences and humanities.

An upgrade of the e-infrastructure could possibly create new opportunities for research collaborations of strategic importance, for example within the framework of the EU research programme Horizon 2020. The possibility of conducting comparative studies between countries and organisation forms, and to follow up and evaluate policy changes, is highly underused, partly due to the lack of necessary e-infrastructure. Suitable e-infrastructures may also facilitate a more effective use of existing geographic and geocoded data in Swedish registers.

Infrastructure financed by the Swedish Research Council

As the Swedish Research Council is currently supporting a large number of database infrastructures, of which several touch upon the same disciplines, many of them are presented together under the titles "Longitudinal investigations of living conditions", "Cohort studies of health", "Databases for studies on ageing" and "Disease-specific databases". The aim is to make these areas easier to review.

CESSDA

The Consortium of European Social Science Data Archives (CESSDA) is a collection of twenty European social sciences data archives and a distributed infrastructure for social science data located in Bergen, Norway (host country). Germany plays a prominent role, with responsibility for central tasks relating to the development of the future CESSDA. Through CESSDA, researchers gain access to data from the European countries, and via the organisation's participation in global data collaborations, Swedish researchers also get access to data from a large number of countries outside of Europe. Sweden has been a member of CESSDA since 1981, through the Swedish National Data Services (SND), and there is currently a large research commitment within CESSDA. CESSDA is currently operating within a Norwegian stock company (CESSDA-AS) but is set to be transformed into an ERIC.

CLARIN

The Common Language Resources and Technology Infrastructure (CLARIN) is a distributed infrastructure based on a network of national centres offering data, processing services and expertise to the research community. The purpose of CLARIN is to build up a research infrastructure (e-Sciences for humanities, social sciences and educational sciences) that is based on language resources and uses language technology tools that can be used in all disciplines in which language data is analysed (such as history, law and psychology). This partly involves data resources in the form of text and audio archives, corpuses (collections of language data), historical sources, newspapers, dictionaries, grammar etc., and partly the technologies and tools needed to store, distribute and process the data resources. The "Knowledge Sharing Infrastructure" is another part of CLARIN's mission. CLARIN is part of the ESFRI road-

map, and in 2012 it became an ERIC with nine paying members along with an observer. SWE-CLARIN is a Swedish node in the European infrastructure CLARIN-ERIC.

ESS

The European Social Survey (ESS) is a researcher-initiated attitude and behaviour survey, and since the start in 2002, it has been conducted seven times in more than 30 European countries, including Sweden. The investigation has three overall aims: to monitor and explain the interaction between the changing social structures and attitudes in Europe, and the ideas and behaviours of its culturally and socially different populations; to increase the comparability of surveys across borders and language barriers; and to develop and implement social indicators parallel to the established financial indicators. ESS has previously been funded in part by the European Commission and the European Science Foundation. After the ESS was transformed into an ERIC, the funding responsibility lies with the national research councils. The eighth round of the ESS will take place in 2016.

EUI

The European University Institute (EUI), located in Florence, Italy, was established by the EU in 1976 to contribute to the preservation of Europe's cultural and scientific heritage. At the institute, research and doctoral education is conducted within economics, history, law, sociology and political science. The funding of EUI does not fall within the joint EU budget, but the member countries pay special member contributions that finance around two thirds of the activities. Nineteen of the EU member countries are members of EUI. Sweden has been a member since 1997, through the Swedish Research Council. Several other countries have association agreements with the EUI.

Historical databases

There are currently a number of different databases for different sorts of historical data. The Swedish Rock Art Research Archives (SHFA) is a national archive for documentation on rock carvings and research at the Department of Historical Studies of the University of Gothenburg. The aim of SHFA is to make modern and historical documentation of rock carvings available to research through the development of a new IT system of research databases. These are then to be made available with an online digital research archive,

and with original documentation in a public visitor's archive. The Demographic Data Base (DDB) is a special unit of Umeå University focusing on data production and research. DDB produces and makes available population databases, primarily based on historical information from parish registers from the 1700s, 1800s and 1900s, but can be linked to modern data, which opens up significant analysis possibilities.

SweCens at the National Archives aims to make the population census available for research. The Scanian Economic Demographic Database (SEDD) 1650–2010 (Lund University), aims to expand and improve an existing research infrastructure, with the goal of promoting new research on population matters from a multidisciplinary perspective. The Swedish Gender and Work database, c. 1550–1800 (Uppsala University) contains historical information on the work of men and women. Dramawebben (the drama web) is a digital resource intended for the research and educational sectors, theatres and the general public. At their website is a catalogue of copyright-free Swedish drama from the 1600s up until modern times. At present, the catalogue contains around 500 plays in various full-text versions. Between 2012–2014, an infrastructure was built, and a new text version that facilitates searches in the dramatic texts, eDrama, will be published.

ISSP

The International Social Survey Program (ISSP) is a researcher-governed comparative project with the task of constructing and implementing internationally comparable attitude surveys. The comparative database that has been built is unique in many ways. It contains data regarding a variety of different attitude areas that have been collected annually since the start in 1985. Over forty countries are currently involved in ISSP, the data of which is openly available to the research community. The investigations also have a clear theoretical framework of a more general nature. Thanks to the long-term construction, the ISSP database now constitutes an essential part of the research community infrastructure.

Longitudinal investigations of living conditions

The Swedish level of living surveys (LNU) is a regular survey where a nationally representative selection of the adult population in Sweden is interviewed about their actual living conditions in relation to a number of areas, such as family, health, education, economy, leisure time, living situation, political participation and employment. The survey has been conducted six times between 1968 and 2010.

The Swedish Longitudinal Occupational Survey of Health (SLOSH) is a unique longitudinal study highlighting the connection between labour market participation, working environment, retirement and health. The study is expected to contribute to better conditions for leading a healthy life and increased knowledge of how the risks of morbidity and ill-health can be reduced both in and outside of working life. The study was initiated in 2006 by the Stress Research Institute of Stockholm University, and is intended to study the complex relationship between labour organisation, working environment, labour market participation and health. SLOSH is based on the 2003, 2005 and, in part, 2007 labour market surveys (AMU).

National In-depth Road Accident Database

The National In-depth Road Accident Database is a planned infrastructure that is to guarantee a long-term collection of current data to enable the analysis of traffic accident data, and to make this data available to Swedish researchers. The data collected over the course of the project will contribute to an increased understanding of the causes of accidents and their consequences. The database will also provide an important foundation for the development and validation of methods and tools that can be used for the development and evaluation of new safety systems. Another activity for which this database will be of vital importance is the possibility of measuring the effects of the safety measures implemented in respect of vehicles, traffic environment and legislation.

SHARE

The Survey of Health Ageing and Retirement in Europe (SHARE) is an interdisciplinary interview survey on health, ageing and retirement in Europe that has been carried out in 21 countries, including Sweden, since 2002. The purpose of SHARE is to increase the understanding of the consequences of demographic ageing. The survey focuses, among other things, on labour supply, maintenance ability, social and financial circumstances, family networks as well as physical and mental health. The SHARE survey includes around 90,000 individuals over the age of 50, and is planned to involve 10 rounds up until 2024. At the European level, SHARE is led by the Munich Center for the Economics of Aging (MEA) at the Max Planck Institute for Social Law and Social Policy. Swedish SHARE is run by Umeå University, the Centre for Population Studies and the Department of Sociology. In March of 2011, SHARE became the first infrastructure in Europe to receive the status of an ERIC. SHARE-S is a Swedish node in the European infrastructure SHARE-ERIC.

SND

The Swedish National Data Services (SND) is tasked with being a national infrastructure for research data from medicine and health science, humanities and social sciences, focusing on collection, quality-assurance, documentation (metadata), archiving, capacity building and service for increased accessibility. The activities are conducted at the University of Gothenburg, which is also a financier along with the Swedish Research Council. As an infrastructure, SND has a general and unique function in Swedish research. SND coordinates the Data Service Infrastructure for the Social Sciences and Humanities (DASISH). In DASISH (2012–2014), all five ESFRI initiatives within the research infrastructure area for social sciences and humanities (CLARIN, DARIAH, CESSDA, ESS och SHARE) collaborate. The aim is to identify possible synergy effects within the development of infrastructure and to find a number of concrete, common activities.

Swedish FrameNet (SweFN++)

The Swedish FrameNet is a project that deals with the creation of a central infrastructure component for Swedish language technology, namely a large and freely accessible dictionary resource with rich linguistic information. The Swedish FrameNet safeguards, integrates and makes available a number of free dictionary resources developed within various projects at different times and by different research groups. The infrastructure also increases the amount of information on the integrated resources with semantic and syntactic information about the words found in the English Berkeley FrameNet (BFN) and a few similar sources for other languages.

UCDP

The Uppsala Conflict Database Program (UCDP) is a world leader when it comes to finding information on war and peace. The database is used by researchers from all over the world. The information is available free of charge at the department website, and can also be downloaded as iOS and Android apps. As academic methods and questions have become increasingly refined, the demand for more detailed data has increased. Researchers and decision-makers need more exact information from different conflicts, for example the number of people killed, under what circumstances and, not least, where in a country this is happening, in order to answer the new questions in a satisfactory way.

ETF

Evaluation Through Follow-up (ETF; Swedish acronym UGU) is the only database of its kind in Sweden within the field of education, and it is also one of the oldest social science databases in the country. Follow-up studies are a step in the national evaluation of the school system, and constitute a basis for researchers, primarily within the research area of social sciences. So far, nine follow-up studies have been initiated based on large and nationally representative random samples from different pupil age groups. The first empirical data collection was carried out in 1961. For each random sample, administrative data and survey information is collected. ETF is an example of a social science database that should already have been secured in terms of long-term funding, however, the necessary mechanisms have not been available. Instead, researchers have had to repeatedly apply for funding for new data collections, etc.

Cohort studies on health

Several databases within the area of humanity, culture and society are based on cohort studies, in which a large number of people are contacted and monitored over time. *Malmös Förenade Befolkningsdatabas* (the Malmö population database) has been conducting large population studies for 37 years, which has made it possible to collect extensive clinical data for more than 50,000 individuals. This applies primarily to the studies Malmö Preventive Project (MFM) and Malmö Diet Cancer (MKC). Data from MFM and MKC has regularly been linked to local, regional and above all national registers belonging to the National Board of Health and Welfare and Statistics Sweden.

Women and alcohol in Gothenburg (WAG) is a prospective, longitudinal population study of occurrence, risk factors, drinking motives and negative consequences relating to alcohol consumption. The interviews deal with the women's working lives, leisure time, family and social situations, but also with previous experiences from their childhood and school years. Everyone in a certain area are included, regardless of whether or not they have psychological problems and irrespective of their alcohol habits.

The Swedish Mammography Cohort (SMC) is an extensive, population-based follow-up study of over 60,000 women in the counties of Västmanland and Uppsala. The study is intended to look at the relationship between a number of changeable factors (including diet, vitamin supplements, physical activity, smoking, alcohol and weight) and the occurrence of a number of chronic diseases. The longitudinal study design and the access to updated exposure data for the participants of the cohort makes it possible to consider changes in lifestyle factors that may influence the risk of various diseases. Follow-up of the cohorts is also managed through registers.

Databases for the study of ageing

The database Population studies of elderly in Gothenburg includes information from population surveys of elderly people conducted in Gothenburg since 1968. These studies consist of psychiatric and physical examinations, family interviews, psychometric tests, personality tests, morbidity data, social circumstances and functional ability, DNA analyses, laboratory investigations, CT scans of the brain, CSF analyses and health records studies. The database is unique in respect of the possible size of the survey groups, the extensive investigations, the long follow-up periods, the high age and the possibility to look at changes in the disease panorama over time.

SNAC-K, a longitudinal Swedish national study on ageing and care in Kungsholmen, aims to conduct an area and individual-based data collection over a longer period of time (30 years or more), which describes ageing, health and the occurrence of healthcare needs from a social, medical and psychological perspective. It also registers what measures the individual receives from the municipal elderly care and the county health services. Data highlighting what measures are taken by family members and volunteer organisations are also gathered. The information is added to a longitudinal database. The aim of this database is to facilitate the monitoring of individuals and the care measures taken in the area over time, in order to study how the need for social and medical care develop, how well they are met and which results are obtained from the measures in a holistic sense.

SATSA, the longitudinal Swedish Adoption/Twin Study of Aging that was initiated in 1984, is a research resource for studies of ageing. A survey with questions relating to childhood and working environments, health, lifestyle factors, personality and social circumstances has been answered by more than 2,000 twins, with three-year intervals up until 2010. In addition to the survey, there is further information from the Swedish Twin Registry, which was collected approximately twenty years prior to the start of SATSA. More than 800 twins have also participated in in-person testing, including cognitive tests, a simple health examination, functional ability tests, and provided blood samples on up to 9 occasions during a 30-year period. SATSA has for example been used to analyse the significance of heritage and the environment when it comes to ageing, especially focusing on memory and reasoning, as well as physical health. SATSA has extensive amount of data relating to ageing, which includes everything from genetics to lifestyle and social circumstances, and which has been collected through repeated measurements over three decades.

The purpose of the Betula Project is to study how memory functions change during adult life, and to determine risk factors and early clinical indications of dementia. The project is longitudinal, with new cohorts added.

The first empirical data collection started in 1988, and a sixth round is to be carried out. The combination of psychological, social and biological variables is of particular interest.

SWEOLD is a nationally representative survey of Sweden's elderly population. The selection consists of people who have previously participated in one of the Swedish level of living surveys (LNU), but who have passed the upper age limit of 75 years. The first data collection took place in 1992 and was followed up three times during the 2000s, being linked to several LNU surveys. This longitudinal database thus offers a chance to monitor individuals over a 40-year period, but can also be used for cross-sectional analyses. SWEOLD contains information on the actual living conditions of the elderly within a number of central areas in their lives, such as health, social and medical care, finances, living situation, occupation and everyday activities. A number of simple tests are included to measure physical and cognitive ability.

Disease-specific databases

All New Diabetics In Scania (ANDIS) and All New Diabetics In Uppsala County (ANDiU) are national databases to promote diabetes research, and they strive to use genetic markers and biomarkers to identify different subsets of diabetics, thereby becoming better at predicting the progress of the disease.

PCBaSe (a Swedish prostate cancer database ACCESS Online access) provides data enrichment for research on large Swedish data bases in which data from the National Prostate Cancer Register of Sweden (NPCR) has been combined with a number of other demographic and medical registers. A system for online access to data is being built, where access is made easy for Swedish and international researchers, while maintaining the security of the data.

TBDReaMDB is a database of mutations in drug-resistant tuberculosis, which is freely accessible through a website. This database is built on extensive systematic literature reviews.

The EIRA database – the significance of environment and living habits for the occurrence and progress of rheumatoid arthritis – is an infrastructure that integrates and develops existing national research databases within the field of chronic inflammatory diseases. The overall goal is to create an infrastructure to facilitate Swedish research on how environment and lifestyle interact with genetic factors when it comes to the risk of disease, progress of the disease (including comorbidity and quality of life), response to therapy and the cost to society of these diseases.

Description of potential new infrastructure

There is a great need to coordinate and consolidate the databases that exist within social sciences and medicine (public health and epidemiology) in the long term. At the same time, there is an urgent need to lay the foundations for the establishment of new infrastructures, not least in the humanities. The motive is simply to be able to answer new research questions. A targeted call for grants to databases within medicine and social sciences will be made already in 2015, with the aim of creating a systematic basis for long-term priorities and coordinated development of these infrastructures at a national level. A new call relating to long-term initiatives in these areas can thereafter be made in 2017. Below is a brief account of the areas' strengths and weaknesses, as well as the challenges and opportunities identified. These considerations have guided the recommendations regarding future calls for applications.

Strengths and weaknesses

Registers for social sciences and medicine/public health

Sweden has a unique potential when it comes to medical/public health science and social science research to use registers based on personal identity numbers. Register-based research has grown significantly in recent years. By combining information from existing registers and adding research data, a number of research questions can be analysed. It is clear that access to high-quality registers offers large competitive advantages for Swedish researchers, as well as for researchers in the other Nordic countries. The modern national identity number-based registers are built upon a century-long tradition of careful data collection on the composition and living conditions of the Swedish population. This means that different historical register databases also constitute a unique infrastructure. The greatest strength of these registers lies in the fact that they often include the total relevant population, that they offer data over long time periods with minimal drop-out rates, and that data can be built both prospectively (studies where morbidity has yet to occur) and retroactively (studies where the outcome is known).

The general systems for health care and social insurance that exist in Sweden also mean that these registers are more comprehensive than in most other countries. Sweden also has a number of world-unique national quality registers with information on the country's major endemic diseases. These

national systems and registers are only marginally affected, if at all, by dropouts, while they fulfil increasing needs within research for longitudinal data and data of a high geographical precision. As decreasing response rates are a reality in most other countries (see below), the access to register data increases Sweden's relative research potential. However, in order to fully utilise this potential, both legal and practical obstacles must be eliminated.

In the first case, this is a matter of achieving an adapted legislation that both meets research requirements and respects the individual's right to integrity. A proposal for how this is to be achieved has recently been submitted by the "Westerberg enquiry" (SOU 2014:45), which has been produced with the expressed purpose of facilitating a more effective use of Swedish research potential, while maintaining the protection of individual integrity.

Practical obstacles include the researcher's limited access to register data and the possibility of linking data gathered by researchers to a register. There are also deficiencies in the coordination between register-keeping authorities, documentation of register data and in some cases in the documentation of data collected by researchers. Increased collaboration between register-keeping authorities and between authorities and researchers is required; a process that has been initiated via the register-based research commission given to the Swedish Research Council (Government Bill 2012/13:30 Chapter 12.4).

Within medicine and public health research, there is a great need to coordinate large population-based surveys. There is a similar need in the social sciences to run large infrastructures in the long-term, rather than collecting specific data for individual projects as the research is increasingly geared towards understanding processes and social mechanisms. Coordination means that infrastructures that fulfil the same purpose are combined, or partially dismantled, but it also means a clear division of labour, so that the existing infrastructures clearly focus on specific tasks. Increased national and international coordination is required to achieve this goal. Above all, it is important for the social sciences, where different countries constitute unique "laboratories", which is why infrastructures such as ESS and SHARE are essential.

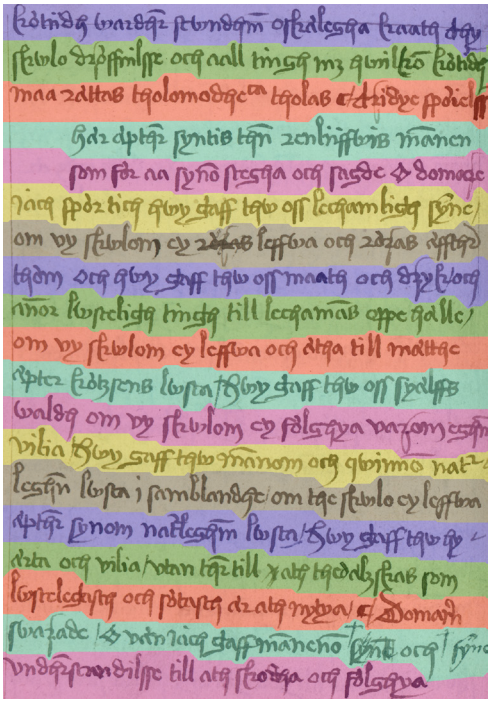
A national process to coordinate Swedish databases focusing on the collection of data has also been initiated, which includes the RFI-ordered investigation "*Nationell samordning av frågeundersökningar och längdsnittsstudier*" (National coordination of survey investigations and longitudinal sectional studies) (2014)[20]. A development towards increased coordination should continue to be reinforced through new calls within this field.

20 *Nationell samordning av frågeundersökningar och längdsnittsstudier*, R. Eriksson, Vetenskapsrådet 2014, ISBN: 978-91-7307-235-9

Databases within the humanities

When it comes to the humanities, archaeology is particularly dependent on methods and analyses from natural science disciplines. These analyses have contributed to a significantly better understanding of the prehistoric development and its chronology, as well as the interaction between humans, nature and climate. The natural science aspect of archaeology has developed quickly, as analysis from a number of methodological advancements like isotope, metal and DNA analysis and hyperspectral imaging and remote analysis are being implemented by the discipline. This is a development that will require both infrastructural investments and a more extensive national and international coordination. Next to this methodological development, there is also an increased desire and infrastructural need for coordination of earlier research and survey results at different levels, for example in the form of database, image and geography information systems and material. Geographical resources are also important for activities directed towards the general public, and for the broader discussion on cultural heritage. One important aspect is to make material available in different languages. The initiatives that have been taken for the coordination of earlier archaeological research results, investigations of rock carvings (SHFA), and various materials with the responsible authorities, are all steps towards an increased national coordination. It is highly important that the construction of e-infrastructure is coordinated with these authorities, such as the National Heritage Board and the National Historical Museums, and for data to be centralised, for example in the SND.

Sweden has a particular strength when it comes to language technology environments that started with the establishment of the Swedish Language Bank, which was placed at the Faculty of Arts at the University of Gothenburg as early as 1975. Swedish membership in CLARIN ERIC is a continuation of that tradition, and it is also of strategic importance to the European collaboration.



Advanced image processing enables reading of ancient handwritten texts that have been scanned and digitized. Image: Fredrik Wahlberg och Anders Brun.

Swedish participation in international studies and surveys

Swedish participation in various international survey programmes create great opportunities for research of the highest quality. Individual data collected in several countries makes it possible to conduct research on the role of public institutions (contextual factors) in social behaviour, but also for health and functional ability. European research has large competitive advantages in this context: the European research laboratory offers an interesting variation between countries in terms of factors such as historical background, culture, language, religion, family and gender systems, economic models, political systems and various aspects of social organisation. There will continue to be an extensive need for collecting research data from individuals. This applies to public health and behavioural science, with self-reported data concerning the individual's perception of their health and life situation, and their ability to handle these. When it comes to health-related research, such as studies of development from infancy to old age, there is also a need to collect physical measurements like weight, blood pressure, grip strength and blood samples, along with measurements of cognitive and perceptive functional disabilities.

Subjective data is highly valuable in social science research.

Surveys are also necessary when studying psychosocial factors, such as social networks, stress and coping strategies. Such investigations can also be combined with information from registers or other data sources, for example by monitoring different life events based on the situation at the time of survey/interview participation. This means that many Swedish surveys get a significantly higher academic value than similar investigations conducted in other countries.

However, the generally decreasing response frequency in the collection of survey or interview data is threatening the quality of data material. As it becomes more difficult to collect survey data, the importance of registers is growing, but it cannot replace self-reported data. One possible future scenario is that there will be fewer, but more expensive survey investigations, as a result of the need to spend resources maintaining high response rates. An investment at the national level to halt the development towards lower response frequencies through better knowledge and technology would be desirable. This includes increased research on respondent motivation as an alternative or supplement to the earlier focus on respondent burden.

Trends and tendencies

Cross-disciplinary research infrastructures

Research within the social sciences, humanities and public health is becoming increasingly interdisciplinary. Fundamental research questions and knowledge needs in society and with decision-makers are increasingly concerned with the general trends in society, such as phenomena relating to an ageing population and global migration, which brings up questions of multilingualism, multiculturalism and integration etc. Increasing socioeconomic gaps and rapidly growing globalisation also means greater demand for new research. The same is true when it comes to altered needs within the health services in terms of facing composite morbidity, psychosocial illness and undesirable trends in the mental ill-health of children and young people. In this respect, the education system and other social institutions are of central importance. There is growing awareness when it comes to the impact of socioeconomic differences on people's health. An area that is particularly urgent to explore is the relationship between society and culture on the one hand and health on the other. To provide a better basis for recommendations to decision-makers regarding necessary measures, a clearer connection is required between

social scientists, behaviourists, cultural scientists, psychologists, physicians and medical scientists. In all these cases, infrastructure is needed to increase cross-disciplinary research. In addition to these coordination needs, there is a need for a continuous supply of data.

When it comes to longitudinal data, the Swedish Research Council has played an important role by supporting various coordination initiatives. Within the social sciences, this includes SHARE, ESS, ISSP, WVS, GGS, SLOSH, CLARIN, ETF and LNU. It is important to be able to work with long time series in order to draw conclusions on long-term relationships and processes. It is therefore becoming increasingly urgent to safeguard databases such as ETF and LNU in the long run. Within the more medically oriented research, there are a long line of longitudinal databases that have been given support. An important trend seen in research is that the borders between medical and social sciences are becoming less and less relevant. A more just designation of this borderland would be "health research". Future infrastructure within health research should therefore be designed to encourage medical researchers wanting to build a new population database to also involve social science experts and vice versa. Social scientists that want to build infrastructure relating to health should collaborate with medical researchers and in both cases, behaviourists should be involved too. There is also great potential in involving the humanities.

Another example of collaboration across disciplines is the one taking place between linguists and psychologists with the help of brain scan data. There is much to gain from Nordic collaboration, but Sweden is responsible for developing resources relating to the Swedish language, and in this, CLARIN and other language databases play a central part.

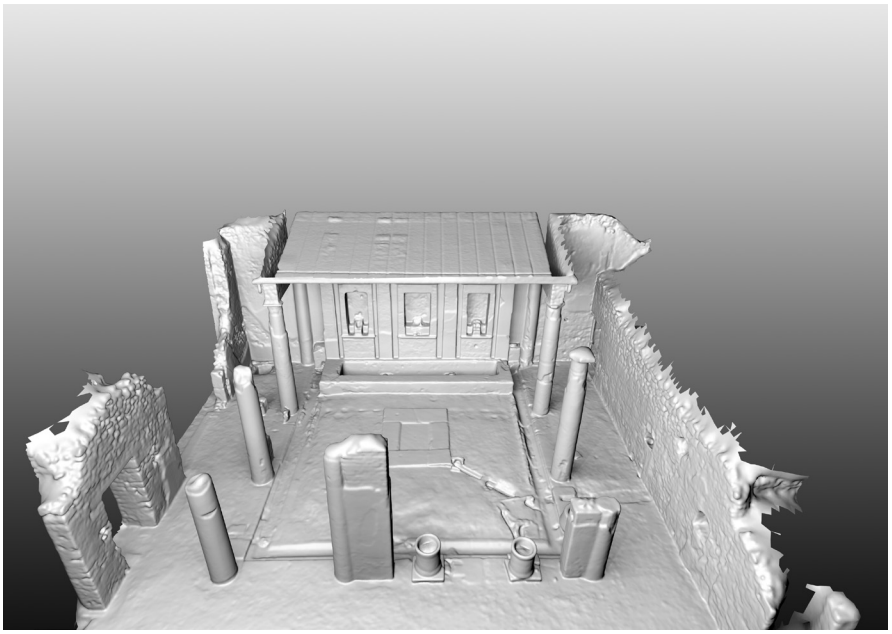
International collaboration

The international trend within social sciences and public health sciences is also headed towards longitudinal and comparative analyses. The comparative analyses, i.e. comparisons of countries and populations, are increasingly dependent on access to individual databases as a supplement for institutional data and the information provided by other countries. International projects are particularly relevant when it comes to social sciences. Comparing countries and populations on the basis of individual data is emerging as an increasingly important practice. SHARE and ESS are examples of researcher-initiated European Research Infrastructure Consortiums (ERIC) spearheading this field. Among the international initiatives supported by the Swedish Research Council are the Generations and Gender Survey (GGS), the International Social Survey Program (ISSP) and the World Values Survey (WVS).

GGS has been carried out in 19 countries, primarily in Europe. ISSP is and has been conducted for a long time, on repeated occasions, in 48 countries, while the WVS has been carried out in a corresponding manner in close to 100 countries. From an international perspective, these infrastructures are thus anything but small, and the Swedish part should be considered a share of an international infrastructure. In the same way that Sweden contributes to and owns small shares in a great number of facilities, the country is contributing to an international structure via these infrastructures. What is lacking on the social science horizon today is a researcher-driven international living standards survey. Currently available is the EU-SILC, which is run by the countries' statistics agencies, but this is limited in terms of content, and its quality is undetermined. CLARIN ERIC demonstrates how language resources can be developed globally via the European collaboration, by inviting universities from outside of the EU. It thereby shows the potential for international collaborations on infrastructure also within the humanities. The review of Swedish development research that the Swedish Research Council has completed emphasises the need to develop data, in parallel to infrastructures such as UCDP, relating to the format of social institutions (including education, health services, insurance) and their mode of operation (e.g., corruption).

Longitudinal population studies

Within the field of human health, perhaps the most important trend is the possibility of conducting longitudinal population studies that tie together clinical health data and social/behavioural data and biological information, and where sociodemographic data is obtained from the SCB registers. Surveys such as EpiHealth, LifeGene, *Västerbottenstudien* (the Västerbotten study) and SCAPIS are all highly interesting. Coordinating biobanks, in order to make them searchable and linkable to data from other registers or collected data, is already underway, for example within the framework of BBMRI.se, but is emerging as an increasingly important task. On the other hand, there is a lack of simple methods of searching for information and linking data from multiple longitudinal cohort studies that have been collected within medicine. Large advances could be made if it was possible to study more rare cases in already collected data, regardless of whether biological samples are available. But there should also be a more active participation, not only from social scientists, but also from behaviourists, psychologists and psychobiologists in the construction of such infrastructures.



An increasing number of sciences use e-infrastructures. One example is the 3D model of the atrium in Casa del Torello in Pompeii, one of the houses in the block of houses that the Swedish Pompeji project has documented since 2000. Image: The Swedish Pompeji project.

Need for e-infrastructure

The humanities, social sciences and health research are to a growing and more rapid extent gaining access to data in digital form. E-Science and e-infrastructure are highly relevant for these areas, since their results and conclusions are directly dependent on the information that can be gained from databases and registers. The preparedness and capability to utilise the opportunities presented by e-infrastructure and e-Science varies greatly. A general capacity increase within the research community is therefore a strategic goal. At the same time, several Swedish research environments have a long-standing tradition when it comes to processing very large amounts of data. A few examples are provided below.

Swedish research institutions are world leaders in both data infrastructure and analysis of military armament (SIPRI) and military conflicts (UCDP). Traditionally this has concerned macro-comparative studies on the national level. In later years databases are constructed on a lower geographical level and with great precision in the time dimension as well. A developed e-

infrastructure in the field should not only improve the competitiveness of these research environments but also create the necessary conditions for new forms of global research collaborations globally and the visualization of data of great relevance, even outside the research community.

Several Swedish university departments are currently conducting comparative research and database building around how public institutions and official politics have been organised in different countries. Quality of Government (QoG) at the University of Gothenburg is one example, and the SCIP (Social Citizenship Indicator program)/SPIN (Social Policy Indicator Database) at Stockholm University is another. An upgrade of Swedish e-infrastructure could increase the competitiveness in this type of research, but also create opportunities for research collaborations of strategic importance. One example is the questions raised within the framework of the EU research programme for 2014–2020, Horizon 2020. Enormous amounts of data concerning individual cases (behaviours, attitudes, conditions) are collected annually. The European research collaboration concerned with analysing the possible sources of differences observable in this respect is still underdeveloped however.

E-infrastructures are not only important for connecting various types of context data to individual data within social science and medicine. Swedish registers also contain information on geographical coordinates to all Swedish properties, which provides a link to the individual's place of residence and work. Optimal use of existing registers requires an increasingly large computation capacity to facilitate further method development within the field.

Within the humanities, the need for large amounts of digital data is growing. In this respect, it would be desirable to have a strategy for the development of e-infrastructure, not least in terms of digitalising texts and inventories at archives and museums. The need for a strategy is general however, and researchers should cooperate with central stakeholders like archives, libraries, museums and cultural heritage sites (ABMK) when it comes to the development of e-Science, which is often referred to within the field as digital humanities. Collecting data online, via surveys and direct observations as well as by analysing secondary data, will probably become an increasingly important practice, which will place demand on e-infrastructure, but at the same time it raises ethical questions with regard to consent and availability time frames. This development is propelled through the CLARIN infrastructure, and a similar development in other areas ought to be the key to completing network analyses, where the humanities interact with social science theory. To develop the humanities laboratories in Lund and Umeå to form a clear part of a national infrastructure, it ought to be of essential importance to develop adequate e-infrastructure.

In the end, the needs for e-infrastructure relate to providing the research community with the tools needed to maintain the values that are to be the foundation of national infrastructures, where open access is the guiding principle.

Recommendations 2015–2020

Promote coordination, consolidation and innovation through targeted calls

In the future, a more extensive coordination will be required between the Swedish Research Council, Swedish universities and other authorities and funding bodies involved in infrastructure. The Swedish Research Council intends to support the construction of innovative and high-quality infrastructures of national interest. However, the future operation of these infrastructures should be managed by higher education institutions and/or other responsible agencies. This will require agreements between the Swedish Research Council and the higher education institutions and agencies involved, to be entered by the time the decision to fund an infrastructure is made. The accessibility of research resources in the form of databases etc. should also be ensured when the infrastructure is constructed, and in this regard, SND plays a central role, as does the register research function under construction at the Swedish Research Council. Investments in e-infrastructure will be of strategic importance to both collaboration between infrastructures and the availability of data.

Thematic contributions to databases within social sciences and medicine: Targeted call 2015

When it comes to social sciences and medicine (public health), a central challenge is the coordination and long-term consolidation of the databases that already exist. The infrastructures that are already of a clear national interest, those that have the potential to be, and the ones that should be better coordinated so as to take on national responsibility, should be identified and provided with resources for developing strategic plans.

What is the best way to achieve a better coordination of infrastructures within medicine and social sciences? How can conditions be created to prioritise long-term investments in new infrastructures? To do this, a bottom-up mobilisation from the research community will be required, which also

involves a commitment from the higher education institutions, without the latter making decisions on prioritisations in the initial stages. This can be achieved through a targeted call in 2015. Grants can be sought for operation and/or national coordination of existing and new national infrastructures. Erikson's (2014)[21] investigation on behalf of the Swedish Research Council points to the area of survey studies, longitudinal studies and cohort studies within medicine and social sciences as urgent areas to coordinate and reinforce in the long term. The aim of the 2015 call is thus to facilitate the coordination of existing databases, but also to provide the conditions for more innovative research projects, where new infrastructures constitute an integral part. Particular consideration should be paid to research across the traditional disciplines.

A targeted call for new national infrastructure pertaining to databases within social sciences and medicine should be launched in 2017. This call would aim to open up for long-term investments in prioritised national infrastructures according to the new model of eight-year grants developed by the Swedish Research Council. Having data collection funded in project form does not result in good continuity, and project-based infrastructures also run the risk of cementing the separation of disciplines. Collection, coordination, quality-assurance, preservation and accessibility of research data are all central factors in achieving an effective coordination of data.

Needs inventory for the upcoming coordination of context databases and humanities databases

There is a need for a better coordination of existing and additional databases of context data, not least to support interdisciplinary research. Metadata in the form of variables can be used for macro-macro analysis, but above all to analyse a number of the individual relationships involving health, inequality and education. A needs inventory is expected to be conducted in 2015, and in the long run, a targeted call for new national infrastructure relating to context databases should take place. Such a call should demand a specification of how social structures, and not least institutional conditions in general and other types of interventions, could be systematically coded in national infrastructures. A needs inventory within the humanities is also necessary in 2015. By coordination databases and building awareness of the benefits of digitally accessible materials, both quality and comparability within historical, cultural and comparative literature studies can be increased. Digital huma-

21 *Nationell samordning av frågeundersökningar och längdsnittsstudier*, R. Eriksson, Vetenskapsrådet 2014, ISBN: 978-91-7307-235-9

nities has stimulated method development on a general level, and has led to the combination of qualitative and quantitative investigations, and in this respect, it is also of high relevance to the field of educational sciences. Otherwise, it is primarily archaeology that has great needs for a functioning national infrastructure to utilise methods from the natural sciences. In the long term, a targeted call for national infrastructure regarding databases within the humanities should also be carried out.

Continued investments in register-based research

Ongoing investments to promote register-based research currently seems to be effective, and it is important that these types of initiatives are allowed to continue. Research is dependent on the supply of methods and expertise, both now and in the future, to establish new databases with longitudinal individual data that can be linked to these registers. A better documentation of existing registers, better possibilities to link data from different register-keepers, as well as faster and more transparent processes to organise such data, should be supported. Furthermore, linking register data from several Nordic countries should be supported. Continued investments in the digitalisations of historic censuses and parish register data should also be made.

SND

During the period 2015–2020, the work to develop the SND in the role as a service organisation will continue. The Swedish Research Council has granted SND operational funding for 2014 and 2015 at more or less the same level as in 2013, and without altering SND's mission. This is an interim state, which is primarily dictated by the Swedish Research Council's Government commission on register research, but also by the enquiry relating to the legal and other conditions for register research headed by Westerberg (SOU 2014:45). In this regard, the policy makers must not only deal with legislative issues relating to researcher access to registers and databases and how the integrity of private individuals is to be protected where this is concerned, but they also have a number of organisational issues to consider. Among other things, Westerberg has suggested an investigation of SND's future organisation. In this context, documentation of medical data constitutes a particular challenge. Since biomaterials are often involved when it comes to medicine, a new legislation will most likely set new demands for the format and organisation of a national coordination. Even if the exact mission and organisation of the SND is still under consideration, the fact remains that SND will constitute an important infrastructure in the future, and should continue

to have a prominent role when it comes to data service, documentation, development of meta standards, education etc. This role can be developed by SND being closely involved in the coordination effort above, thereby fortifying its role in future infrastructure for databases within the humanities, medicine and social sciences.

Development of e-infrastructure

The research areas described above presupposes an e-infrastructure in which data at different levels and from different sources can be connected. It is furthermore of urgent importance, not least on the European research front, to be able to utilise modern e-infrastructure to support a development of these kinds of collaborations. A new type of e-infrastructure would be necessary in order to analyse institutional and other contextual effects on a broad front. There is also a potential to develop research and methods that combine the strengths of various aspects of longitudinal and geocoded individual data. It is therefore important to invest resources into further outlining and analysing how strategic e-infrastructure investments could contribute to breaking new ground in other areas. There is a need to raise the competence within the research community when it comes to the ability to use modern e-infrastructure. The thematic applications called for above should contain an explicit plan for the development of e-infrastructure. At the same time, it is important to consider one of the main conclusions from the Ynnerman enquiry conducted on behalf of the Swedish Research Council (2014): individual research groups cannot be expected to have expert knowledge of e-Science, data documentation, coordination, etc.

Online data collection methods facilitate the collection of self-reported individual data. This contributes to a rapid development towards the processing of large amounts of data within research, i.e., Big Data. Within longitudinal cohort studies, data collection more and more often takes place through online surveys or information management systems. The possibilities of developing different forms of online data collection within the framework of the supported infrastructures should be investigated. The possibility of systematically analysing enormous amounts of data that are available is rapidly developing, and may benefit developments within the humanities and medicine as well as social sciences. For this reason, there is cause to investigate how the analysis capacity can be strengthened as part of a national e-infrastructure.

LIFE SCIENCES

Description of the field

Research within the life sciences aims to increase our understanding of how all living organisms function, interact and influence their environment. Biology and medicine are important fields within life sciences today. The fundamental research uses different model organisms as well as genetics, genomics, proteomics and a large number of measuring methods integrated with computational biology to outline the function of organisms at the systemic and molecular level. Complex biological processes can currently be studied thanks to a rapid technology development taking place in parallel to basic scientific research. The positive development makes it possible to achieve faster results, but it is also increasingly dependent on multidisciplinary collaborations and access to biological materials. The research results find their use primarily within medical diagnostics, prevention and therapy, but also within plant research and biotechnology. In many cases, the results are also applicable in interaction with researchers from various disciplines other than medicine and biology, such as technology, chemistry, physics, materials science and pharmacology. Living conditions and environmental aspects are also important components.

Modern-day research within life sciences is characterised to a great extent by crossing boundaries, international activity and requires access to infrastructures and expertise. The development of new national infrastructure to meet these needs has shaped the field over the last five-year period. A few examples include the technology platforms constructed within the Science for Life Laboratory (SciLifeLab) for research on questions relating to DNA, RNA and proteins. The Swedish Research Council contributes to the construction and operation of several of these technology platforms, along with several other major financiers, including universities and KAW. In order to create a long-term and national development, collaboration between these and other stakeholders will be necessary.

Life science infrastructures often consist of networks with nodes in multiple locations (known as distributed infrastructures) based on different technologies and resources. Examples of such infrastructures include BILS for bioinformatics, the National Genomics Infrastructure (NGI) for DNA and RNA sequencing, and the Biobanking and Molecular Resource Infrastructure of Sweden (BBMRI.se) for biobanks. But infrastructures in the form of larger

facilities used to study structures and molecular interactions will also be important in pushing the development forward. Among others, MAX IV and the European Spallation Source (ESS), which are currently under construction in Lund, are expected to provide brand new opportunities. Sweden has long been considered a goldmine for research within the life sciences by virtue of its rich databases and registers, as well as its access to large sample collections which stretch far back in time. A lack of coordination has to some extent constituted an obstacle to optimal utilisation of these resources, and the work to create a cohesive structure in Sweden, the Nordic countries and Europe will be a decisive factor of a continued positive development. One important part in this work is the development of national structures to make data accessible to researchers in ways that fulfil research requirements while also providing adequate protection of individual integrity, in cases where data originates from patients or healthy volunteers.

The growing amounts of data generated by life science research provide new opportunities in terms of extracting information. At the same time, significant resources and new skills are required within statistics, bioinformatics and analysis of large datasets, i.e. Big Data. All the infrastructures within the life sciences are, and will continue to be, completely dependent on the developments within e-Science. Tools for storage, analysis and computation of large amounts of data will be decisive for the research field and its applications. Associated training and expertise needs to be developed and maintained for the future.

The European infrastructure collaborations within life sciences, especially the ones proposed by ESFRI, are – and will likely remain – highly influential in the formulation of calls within Horizon 2020 and in the preparation of the next framework programme. Sweden's ability to participate effectively in this development requires the consolidation and integration of national infrastructures into the European investments in an open process that corresponds to research needs.

Infrastructure financed by the Swedish Research Council

BBMRI-ERIC

The Biobanking and Biomolecular Resources Research Infrastructure (BBMRI-ERIC) is a joint organisation for biobanks in 14 European countries since 2013. The goal is to make large amounts of biological samples accessible to research and development of health services, and to highlight Europe's joint

resources from a global perspective. Through its various nodes among all the member countries, the infrastructure covers a large and varied supply of well-characterised biological samples, which can be expected to increase the value of the sample collections and the possibilities for larger international collaborations. Within the framework of BBMRI-ERIC, the member countries are funding a coordinating head office in Graz, Austria, along with a few common services.

BBMRI.se

BBMRI.se (Swedish Biobanking and Biomolecular Resources Research Infrastructure) is a distributed infrastructure with nodes at all the major higher education institutions in Sweden that have a medical faculty. The activities are intended to increase national coordination of the collection and storage of data and biological samples from patients and healthy volunteers, and the access to these resources for research purposes. Samples are provided for analysis according to academic priority and ethical approval. The infrastructure thus provides opportunities to more effectively study disease mechanisms and biomarkers on a larger material, and thereby facilitate the development of new treatment strategies adapted to identified patient groups. BBMRI.se operates by coordinating and making available biobanks from universities and county councils, and setting up a national organisation for standardised sample and data management that adheres to ethical and legal guidelines. They also provide expert assistance for new collections, as a support for researchers with no prior experience from this type of study. BBMRI.se is a Swedish node in the European infrastructure BBMRI-ERIC.

BILS

The Bioinformatic Infrastructure for Life Sciences (BILS) is a distributed infrastructure that supports a number of selected projects at all the major Swedish universities and SciLifeLab. In 2014, BILS involves around 35 positions funded by BILS and the different host universities. The majority of activities focus on bioinformatics support within DNA and RNA sequencing projects, but BILS also provides support within proteomics, genetic networks, metabolomics and, on a smaller scale, system biology. BILS offers access to a number of tools (software, algorithms) via its website bils.se, as well as associated user support. BILS supplies and maintains bioinformatic methods and provides training within bioinformatics.

Another bioinformatics infrastructure is funded by KAW: WABI (Wallenberg Advanced Bioinformatics Infrastructure) which is located at SciLifeLab. WABI's profile differs somewhat from that of BILS, but in the long term, an

integrated development and coordination of the different bioinformatics structures will be required. Bioinformatics support is also available within the infrastructure SNIC (see section on e-Science) at UPPNEX in Uppsala. This bioinformatics support is not fully covered at present, and the need for support will increase significantly in coming years.

BILS is the Swedish contact for the European bioinformatics infrastructure ELIXIR.

CBCS

The Chemical Biology Consortium Sweden (CBCS) is a distributed national infrastructure for chemical biology, which includes work on the development of small organic molecules to be used as research tools. The activities are based on screening collections of these organic molecules for biological activities in testing systems and biological models included in user projects. Biologically active compounds are optimised and characterised in respect of parameters that are important to biological experiments in animal models, such as membrane permeability and metabolic stability. The operation was started in 2010 and is run by Karolinska Institutet, Umeå University and Uppsala University. CBCS is currently fully operational. An open application procedure with an independent project review group guarantees general and quality-assured access to the infrastructure. CBCS has users within preclinical medical research and several areas within the natural sciences at all major Swedish universities.

CBCS is included in SciLifeLab as a distributed infrastructure, and participates as an observer in the preparatory discussions for the European infrastructure EU-Openscreen.

CyTOF™

National equipment for single-cell mass cytometry (CyTOF™) at Linköping University provides opportunities for advanced proteomic analysis of cells. By colouring cells with specific antibodies bound to special metals, the presence of a large number of different proteins can be detected in the cells. Using a time-of-flight analyser, a cell can be analysed with single-cell mass cytometry. The equipment allows for the measurement of 45 different parameters of 500 to 1,000 cells per second. This method is therefore perfectly suited for measuring different cell components and different molecular compounds, such as drug candidates, for individual cells. The strength of the method is its great sensitivity, which makes possible the analysis of single cells. A limiting factor is the supply of suitable antibodies.

Similar equipment is available at other Swedish universities, and coordination for national access to these is a possibility that should be investigated.

ELIXIR

ELIXIR is the European infrastructure for bioinformatics. ELIXIR is currently in the construction phase, and consists of nodes in various countries, including several of Europe's leading bioinformatics centres, and the activities are coordinated from the node at the European Bioinformatics Institute (EBI) in Cambridge. Sweden is officially participating in the project, and BILS is acting as the Swedish contact point. Sweden contributes to ELIXIR through the project Human Protein Atlas, which aims to map the human proteome. Services offered by ELIXIR includes tools for the analysis of biological data, data storage, including method and standards development, as well as associated training. ELIXIR will integrate bioinformatics services and resources provided by the different nodes with the functions already offered by EBI.

EMBL

The European Molecular Biology Laboratory (EMBL), which celebrated its 50th anniversary in 2014, is a molecular biological laboratory in Heidelberg with a prominent international profile. A number of countries in Europe, including Sweden, contribute funds. The researchers of these countries, primarily promising young researchers, can come to EMBL to establish themselves or to participate in courses or other education programmes. EMBL operates a number of laboratories for microscopy, genomics and proteomics, as well as bioinformatics. From the start, EMBL has been supplemented with a number of nodes, called outstations, which provides services for researchers from all over Europe: The European Bioinformatics Institute (EBI) for bioinformatics in England, the synchrotron light facility Petra III for structural biology in Germany, the synchrotron light facility ESRF in France and a laboratory for mouse biology in Italy. Discussions are underway regarding the expansion of the network with a node for molecular medicine in Barcelona.

EMBL also runs a Nordic network with a node in Umeå (see MIMS). This network is supported by Nordforsk as a Nordic Network of National Centres of Excellence (NCE), and promotes collaboration and exchange among the Nordic nodes FIMM, NCMM, DANDRITE and MIMS, and between these nodes and EMBL.

EMBL is closely linked to the European Molecular Biology Organisation (EMBO), which publishes scientific journals and conducts course and conference activities as well as a scholarship programme.

INCF

The International Neuroinformatics Coordinating Facility (INCF) is an international infrastructure initiated by the OECD. It is coordinated from Sweden (KI and KTH) and promotes open access to data, bioinformatics and modelling tools for research within neuroscience. INCF integrates information from different levels of neuroscience research; from basic understanding of brain functions to the treatment of neurological diseases. The aim is to facilitate neuroscience research globally and to increase the interaction between various stakeholders and groups whilst evaluating various activities within neuroinformatics, including a digital brain atlas, standards and ontologies, and facilitating education within the field. These activities are closely related to the area of systems biology in terms of modelling and simulation. INCF is funded by its member countries. The Swedish financiers, in addition to the host universities of Karolinska Institutet and the Royal Institute of Technology, consist of the Swedish Research Council and the Swedish Foundation for Strategic Research (SSF).

Instruct

International collaboration is important when it comes to structural biology, where the equipment is generally very complex and costly. The European infrastructure for structural biology (Instruct) is a European network with a main office in Oxford, England. Organisations from 11 member countries make 144 platforms for structural biology available to researchers from the member countries. These nodes include resources for protein production, protein characterisation, structural analysis and data analysis, along with an extensive expert base to assist researchers with different solutions to their questions. Instruct provides a common portal for applications to use the equipment and expertise of the different nodes for different research projects. After a scientific evaluation process, the researchers get a time slot, often combined with financial support, to use suitable equipment to answer the problem in question. There are important links between Instruct and other infrastructures, for example for mass spectrometry, imaging and bioinformatics. Sweden also participates in other infrastructures supporting research within structural biology, primarily different large synchrotron light facilities. Sweden has been a member of Instruct since December 2013.

MIMS

The Laboratory for Molecular Infection Medicine (MIMS) constitutes the Swedish node of the Nordic EMBL Partnership for Molecular Medicine. The goal of the Nordic EMBL collaboration is to facilitate and institutionalise academic exchange and support within areas of common interest. MIMS has been established within the Umeå Centre for Microbial Research (UCMR), an interdisciplinary centre of excellence within infection biology, with more than 50 associated principal investigators. The research focuses on molecular mechanisms of infectious diseases with the overall aim of developing new and sustainable antimicrobial strategies to ward off infection and antibiotic resistance.

MIMS is intended to reinforce Swedish research by promoting opportunities for young researchers in accordance with the "EMBL model". This includes international recruitment of young top researchers who receive resources over a five + four-year period to establish a research group with ground-breaking research.

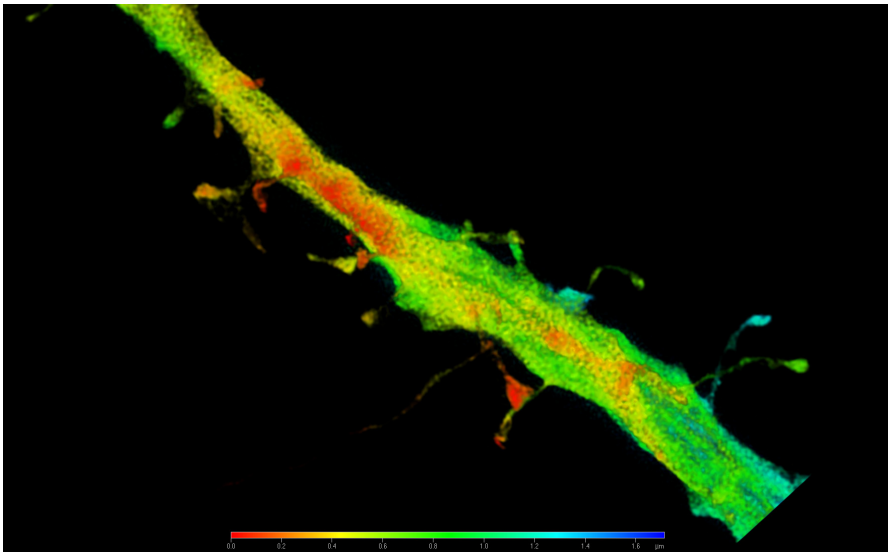
NGI

The National Genomics Infrastructure (NGI, formerly SNISS) is funded as a national infrastructure at Uppsala University and KTH since January 2010. The activities are intended to give Swedish researchers access to the latest technology for large-scale DNA sequencing. Large-scale analysis of DNA and RNA sequences plays a central role within biomedical research. Access to a broad selection of different sequencing technologies makes it possible to choose the combination best suited to a specific task. NGI constitutes one of the three largest genomics centres in Europe, and thanks to its location at SciLifeLab in Stockholm and Uppsala, it can make use of shared equipment and expertise. Furthermore, NGI is collaborating with other initiatives of a national nature, with BILS within bioinformatics and with the SNIC centre in Uppsala, the *Uppsala Multidisciplinary Center for Advanced Computational Science* (Uppmax), when it comes to data analysis and storage. NGI offers expertise within bioinformatics and statistics to ensure optimal experimental design and academically productive projects. The consulting role of NGI is one of the infrastructure's main tasks, which can be developed further. A development of the NGI activities with nodes at other universities, with supplementary infrastructure, is being planned in consultation with the concerned universities (mapping of the human genome, populations of [micro]organisms, and mapping of different plant and animal species).

SCAPIS

The Swedish cardiopulmonary bioimage study (SCAPIS) is a large-scale initiative to collect data on cardiovascular and pulmonary diseases. SCAPIS is to be performed at five nodes in Sweden, and is funded by multiple financers, including the Swedish Heart-Lung Foundation, KAW, Vinnova, the Swedish Research Council and the Swedish university hospitals. The aim is to collect information on many different clinical parameters and personal data from a large number of individuals, in order to then facilitate research on cardiovascular diseases, chronic obstructive pulmonary disease (COPD) and other pulmonary diseases. Its strength lies in the size of the collected material and patient characterisation through well-planned examination methods, including ultramodern CT scans.

In addition to a database, SCAPIS also includes a biobank of blood samples, which will provide a unique source of knowledge on disease mechanisms and biomarkers. A pilot study has been conducted by the node in Göteborg, with very interesting results. Work has begun to gradually build the individual nodes.



The image illustrates the use of the techniques of super-resolving fluorescence microscopy to study small structures in neurons (here super-resolution structured illumination microscopy, SR-SIM). Image: Centre of Cellular Imaging, Gothenburg.

Swedish Bioimaging

Swedish Bioimaging (Swedish national infrastructure for bioimaging) is a national network coordinated by Linköping University, the activities of which are intended to support and coordinate operation and use of Swedish equipment and methodology for biological and medical imaging. Facilities linked to Swedish Bioimaging are found at all the major Swedish higher education institutions that have a medical faculty. Most of the platforms are openly accessible to Swedish researchers, but there is also a number of specialised platforms that are partially accessible to Swedish researchers. Several platforms listed under Swedish Bioimaging are currently of a local nature. Swedish Bioimaging has the ambition of developing its activities into a national umbrella organisation for imaging infrastructures. The activities will be affected by the new initiatives taken with regard to investment in and coordination of equipment for biological and medical imaging.

Biological and medical imaging includes a large number of technologies for microscopy as well as full body scans. The activities furthermore require storage, accessibility of data and image processing with the help of computer programmes/computational biology as well as quantification and development of new probes. The connection to other types of infrastructure, such as mass spectrometry, structural biology, metabolomics, and not least bioinformatics/systems biology is evident. The infrastructure activities also include the development and accessibility of detection markers, such as fluorescent molecules or other specifically marked molecules. Clinical and pathological imaging with the help of different sources of radiation also fall under biological imaging, however, these are not generally conducted for research purposes but within clinical activities.

Swedish Bioimaging is currently the Swedish contact point for the European project Euro-BioImaging.

Swedstruct

The Swedish national infrastructure for structural biology (Swedstruct) is a national infrastructure for protein structural biology, consisting of three nodes:

- the protein production activities at Karolinska Institutet (linked to SciLifeLab)
- two beamlines at the existing MAX II synchrotron and one beamline for macromolecular crystallography (BIOMAX) at the new MAX IV laboratory in Lund

- the Swedish NMR centre at the University of Gothenburg.

The goal is to create a common entry point for researchers within structural biology, to facilitate and increase the access to equipment and expertise through collaboration. Through its three nodes, Swedstruct can offer a full link from protein production, via sample treatment, to the optimal structural biology method for a specific research question.

Swedstruct will function as a node of the European infrastructure Instruct, in which Sweden became a member at the end of 2013. Via Instruct, Swedish researchers gain access to a large number of technology platforms and expertise ranging from production, sample treatment and characterisation to structural and data analysis (see separate description of Instruct).

Description of potential new infrastructure

National coordination of biobanks, databases and registers

Research within the life sciences is highly dependent on access to information on biological materials and individual data. There is currently a very large number of databases, registers and sample collections, which constitute important sources of new knowledge through research in Sweden. If these resources can be highlighted, linked, formatted and made accessible in a manner appropriate to the research, both in terms of human samples and samples from animals and plants, this would most likely contribute to increased quality and impact for Swedish research within a number of different fields. An infrastructure to coordinate these resources needs to be constructed over time. This infrastructure must safeguard and develop the value of the resources that are already available, in order to then supplement them with new data for a long time to come. Components that need to be included in a new infrastructure in the long term are:

- One or a few common portals for access to research data, supported by the different stakeholders providing data for research within the life sciences.

- Standardised and quality-assured methods for data and sample management, which are supported by the different stakeholders providing data and samples for research within the life sciences.

- An organisation with a clear national governance, and a national distribution of roles and responsibilities for the various stakeholders providing data and samples for research within the life sciences.

One step in the continued work to achieve coordination of existing databases and registers is a call in 2015 for support to databases within medicine and social sciences.

Other initiatives are also needed, both at the political and operational levels, to create a common Swedish biobank structure that contains data and samples from research and health services, within public health and veterinary medicine.

Infrastructure for laboratory animals and model organisms

A Swedish national infrastructure for research using laboratory animals and model organisms, both plant and animal, needs to be set up. This requires dialogue and active participation from the different stakeholders in Sweden, primarily the higher education institutions, which currently have equipment and expertise of national interest in this field. A national infrastructure is required as an academic counterpart to Swedish participation in the European infrastructure Infrafrontier. Sweden should consider becoming a member of this infrastructure in order to utilise and contribute to the important knowledge bank for different mouse strains that is being created in Europe. From a longer perspective, an expansion to several model systems may be motivated. There are several examples of prominent Swedish research concerning animals other than mice, and also various plants, for which standardised sample collections and associated data collection would need to be created at the national level.

Infrafrontier was one of the first pan-European infrastructure projects to be presented by the ESFRI, and it was founded by five member countries in April of 2013. The goal of the activities is to coordinate and support the development and use of different mouse models for research purposes. This is to result in a more effective management, which saves money and animals, while also leading to various synergy effects. The infrastructure uses a website to provide information and access to data, biological materials, analysis platforms and expertise. Research groups and science projects in the various member countries gain access to the infrastructure through a peer-review-based application process to assess the scientific quality. Infrafrontier also coordinates larger international initiatives to safeguard the collective resources, in order to facilitate extensive projects which could not otherwise have been executed.

Strengths and weaknesses

Historically speaking, Sweden has been a leading country within several areas of medicine, biology and medical technology. Sweden is currently investing comparatively large resources in life science research, and needs to find ways to administer its resources and knowledge. Tomorrow's challenges and opportunities are about finding and utilising global possibilities. Strategies to maintain a competitive Swedish research therefore need to be reviewed. Part of the Swedish strategy needs to involve well-planned, effective and focused investments into national infrastructure. But active Swedish involvement in international initiatives will also provide influence and access for Swedish researchers to important tools and networks. Existing infrastructures cover important needs, but the organisation of national infrastructure may need to be changed, in order to effectively make resources available and support Swedish research.

Biobanks, databases and registers

Until quite recently, Sweden and the neighbouring Nordic countries have been at the forefront when it comes to biobanks. However, the rapid international development and the realisation that coordination of large amounts of data and sample collections entails a significantly higher possibility of successfully tackling medical questions have meant the Nordic countries are not leading by as much as before.

The Swedish biobanks and associated data are in a state of fragmentation and lacking coordination at the national level. Among other problems, there is no national plan for long-term funding, coordination and simplified legislation to support biobank-based research and the use of databases and registers for research purposes. Important initiatives towards this end are the formation of the national infrastructure BBMRI.se, where all the major higher education institutions with a medical faculty are participating, as well as the work to create increased collaboration at the national level between the biobank activities of the research sector and the health services; a joint Swedish biobank structure (GSB). Processes to streamline and open up access to biobanks and registers are underway, but much remains to be done. Sweden must collect and organise its resources in order to continue being an important player in the international initiatives that are now being started. Sweden also has biobanks where animal samples are collected and saved for research. These sample collections to some degree have different requirements, for example in terms of ethical and legal aspects, but they are highly important to research within biology, veterinary medicine

and other medical research, and should also be possible to coordinate with the human biobanks and data structures.

It is also of central importance that Sweden is actively involved and influencing the international discussions being held to facilitate a more extensive European coordination and collaboration regarding biobanks and registers. Ethics and legality will be among the important issues of international collaborations on biological materials of various kinds. With the vision for Swedish research to have a greater distinction and involvement in the development of products and processes, it is necessary for Europe to take a united approach to ethical and legal questions. Through its membership in BBMRI-ERIC, Sweden should contribute with opinions and expertise.

Need for national infrastructure for mass spectrometry and microscopy

The development within imaging technologies for humans and animals has led to new possibilities of tackling advanced biological and medical questions. The purpose of these methods is to highlight things that are otherwise invisible to the human eyes, or things that are to be quantified. Modern bioimaging often requires digital processing for analysis, storage and provision of data. It thereby has ties to e-infrastructure, mass spectrometry and structural biology, and plays a prominent role in metabolomics and systems biology.

Mass spectrometry includes a number of different methods which facilitate the discovery and quantification of various types of biomolecules and their derivatives (such as modified proteins) in complex biological samples. All higher education institutions conducting significant research in life sciences need to cover their needs for mass spectrometry measuring methods. The development within this field is extremely fast, which means that cutting-edge equipment and expertise cannot be available at all the universities in the country. In many cases, equipment and expertise is highly specialised towards certain types of samples or molecules, and should be organised within a distributed national infrastructure.

In 2012, the Swedish Research Council launched two one-man enquiries to investigate the possibilities for national coordination within these areas; one within biomicroscopy and one within biological mass spectrometry. In both cases, the results point to a great need for national coordination, so that expensive and advanced technology can benefit Swedish researchers

from all over the country[22] [23]. At the same time, basic equipment needed to conduct research within the field is provided locally and regionally by each individual university. New possibilities will also be created within these fields once the facilities MAX IV and ESS are up and running. A very important piece of the puzzle when it comes to utilising Swedish investments will be to make sure that they are also used by new user groups.

During the autumn of 2014, the Swedish Research Council issued a call relating to targeted grants to coordinate some of the most advanced equipment available at Swedish higher education institutions. Two national initiatives were taken, funded by the Swedish Research Council along with the higher education institutions: one within microscopy for the life sciences and one within biological mass spectrometry.

Animal models

The use of animal models within biological and medical research is an important, but also very costly and complex practice. Most of this work is currently undertaken at several Swedish research laboratories without any interaction between them. In Sweden, there are a few universities that have invested in relevant equipment and expert staff, including the Karolinska Institute, which runs the European Mouse Mutant Archive (EMMA), the task of which is to freeze biological material from different mouse strains (primarily sperm and embryos). The pharmaceutical company AstraZeneca, which has operations in Sweden, has long been conducting both mouse phenotyping and pharmaceutical phenotyping, to use as a basis in its drug development. There are also several other centres in Sweden that conduct research on various animal models, such as domestic and farm animals (SLU), pets and smaller species like *Drosophila* and C. *elegans*. This diversity is important when it comes to allowing a wide spectrum of biological and medical studies to be conducted.

There is currently no national coordination for common resources within this field in Sweden, which is a great weakness.

22 *Nationell samordning av biologisk masspektrometri*, G. Hansson, Vetenskapsrådet, 2014, ISBN: 978-91-7307-229-8

23 *Möjligheter till samordning av mikroskopi inom livsvetenskaperna*, K-E Magnusson, Vetenskapsrådet, 2014, ISBN: 978-91-7307-241-0

Need for e-infrastructure

Many speak of a paradigm shift within research, in the sense that today and in the future, research is increasingly conducted by collecting large amounts of data, with no preconditions, which can then be used broadly for analysis using statistical methods and visualisation of data, and with models and simulations. Furthermore, there is a great need to link patient data and clinical data to genetic and molecular networks developed within basic research, in order to develop diagnosis, prevention and treatment methods within the field of "personalised medicine".

The explosive development of large and complex datasets entails a number of demands for new technical solutions and resources for correct and effective data management. A report from Anders Ynnerman has outlined future needs for e-infrastructure in various fields[24]. This report notes that a number of measures are required, within the life sciences for example, to achieve functional e-infrastructure. Existing structures such as Swedstore and Uppmax (SNIC) are currently coping with this task, but the expansions within the fields of genomics, systems biology, proteomics, clinical research, structural biology and image analysis will significantly increase the demands for e-infrastructure. The challenges lie primarily in storage, data extraction and data interpretation, as well as in simulations and predictions of large data models on networks and processes, up to cell and full-body level. Large-scale data management within the life sciences also makes demands regarding security and integrity for patients and healthy sample donors.

A review is needed of the stakeholders involved and of which components are needed nationally and locally to form an adequate e-infrastructure for the different parts of Swedish life science research.

Trends and tendencies

The development of infrastructures for life science research is reshaping the research landscape

We are currently seeing a shift within the life sciences, where research groups are to a decreasing extent defined by the equipment at their disposal within their own or nearby laboratories. Advanced equipment and expertise in using it are instead made accessible through local or national facilities

24 *Science cases for e-infrastructures*, A. Ynnerman, Vetenskapsrådet 2014, ISBN: 978-91-7307-240-3

and laboratories. In the future, research groups will be defined by their ideas and their ability to utilise the best suited equipment to solve complex problems.

The shift towards coordination of equipment within platforms and the creation of a national infrastructure is in many cases somewhat controversial, which means that a new research culture needs to be created. The possible benefits for individual research groups created by infrastructure initiatives need to be communicated more clearly than has been the case so far. Today, there is a large number of infrastructures intended for biological and medical research, both at the national and international levels. The large majority of these are relatively new or under construction. This reflects on the one hand a very rapid technological development over the last ten years that has made available advanced equipment and high-performance systems suitable for use by multiple research groups (for example in imaging and DNA sequencing), and on the other, a new working method characterised by interdisciplinarity and cross-boundary collaboration, often in international contexts. The questions that the researchers are attempting to answer often lie at a level that requires the participation of many different research groups with different expertise. Joint infrastructures have been recognised as a natural part of the research landscape within the life sciences. At the same time, issues relating to the application and function of the infrastructures in research still need to be clarified in order to optimise use. This is a matter of researchers being able to see the benefit of joint initiatives and of continuously adapting the infrastructures to research needs. The decisive factors in being a national infrastructure are availability, quality and expertise. It is therefore important to maintain and develop the expertise of the staff at these infrastructures. Academic infrastructures should be evaluated when commercial stakeholders are able to take over. Education and communication will become important components of the national responsibility.

The trend towards national collaboration and large-scale initiatives is also clear from the very large national resources being allocated to infrastructure initiatives at individual universities and locations within various fields. Examples of such initiatives include the European Spallation Source (ESS), MAX IV in Lund and, within the life sciences, the construction of SciLifeLab in the Uppsala-Stockholm region. These, and similar facilities, will facilitate structural studies at the molecular and atomic level of biological materials. New possibilities will be offered when it comes to studies of protein dynamics, bioimaging, membranes and other bioactive surfaces, and complexes in solutions, such as protons and water molecules in the active sites of an enzyme. This entails new opportunities to understand underlying biological

processes, and increased chances to develop effective drugs (more about these technologies in the section on materials science).

These are important initiatives to strengthen Swedish research, and it is highly important that this type of large investments actually come to benefit researchers from all over the country, in order to deter a depletion of expertise and education in locations that are not direct recipients of the investments. A maintained dispersion of expertise is a central aspect of regeneration and diversity within basic research. This is of decisive importance when it comes to securing future research and research environments. One way of achieving national benefit, which is currently being done at SciLifeLab, is to build up satellite activities in several locations linked to the national investments. Collaboration between national infrastructures funded by different funding bodies also needs to be reinforced, and the lines between infrastructure and research must be clarified, to ensure that resources are distributed in a transparent way and in the best interests of research.

It will be very important to highlight the impact that ongoing and planned research initiatives will have on Sweden's future research landscape.

A similar development towards collaboration and large-scale operations is happening internationally, and it is important for Sweden to increase its involvement and support in the European collaborations within life sciences. Sweden's insight is currently limited to a few European infrastructure projects within the life sciences.

Life science research is often translational, meaning that it deals with transferring new knowledge into measures to improve health services. The research is characterised by multidisciplinary national and international collaborations, which makes it dependent on the European networks and infrastructures being constructed, largely within ESFRI. It also needs to be supported on a strategic level. The national support for infrastructures that specifically work with translational research needs to be reviewed, and Sweden should also carefully monitor and seek to influence the development of European organisations within life sciences of a translational nature (such as EATRIS, ECRIN and ISBE). In addition to expertise and networks, this will also lead to greater insight and influence when it comes to calls within Horizon 2020 and future framework programmes for this type of research.

The use of animals, and particularly genetically modified ones, is increasing considerably. This increase comes with large maintenance costs. Cataloguing and freezing strains will on the one hand reduce these maintenance costs, as animals that are not used are kept frozen until new questions arise, and will on the other hand ensure access to specific animal strains.

Coordination of fields and infrastructures

One consequence of the increased understanding of complex biological systems and the possibility to co-analyse an increasing amount of data, is the emergence of new broad and complex research areas. Translational research is based on knowledge within several more traditional research areas, and pushes the research front forwards, both by generating new ideas within basic research and by acting as an engine for realising new discoveries in improved health services. In all cases, these areas demand an increased coordination of several different infrastructures. Examples of such areas would be metabolomics and systems biology. Below is a description of these emerging fields, and the infrastructure they concern.

Metabolomics includes the detection and quantification of metabolites in cellular extracts or living cells using a number of methods/instruments from other platforms/infrastructures: mass spectrometry, bioimaging, NMR, bioinformatics and systems biology. There are currently two platforms within the field, which receive funding from KAW:

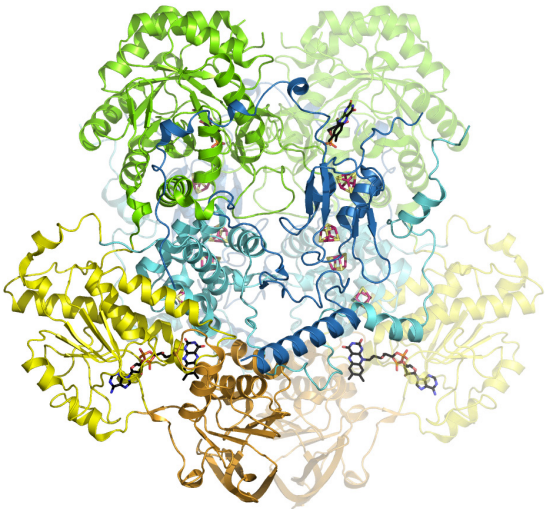
- The Swedish Metabolomics Centre (SMC) is coordinated by Umeå University, and also includes the Swedish University of Agricultural Sciences, the University of Gothenburg and Chalmers. The centre focuses on different mass spectrometry methods, and large emphasis is placed on sample treatment (for example with the help of liquid chromatography and gas chromatography) and data analysis. The Swedish NMR Centre at the University of Gothenburg is part of SMC, and carries out analyses using various NMR instruments. Traditionally, much emphasis is placed on plant research (Umeå Plant Science Centre). Chalmer's part involves bioinformatics, primarily modelling and systems biology.

- The National Center for Imaging Mass Spectrometry (NCIMS) uses mass spectrometry for imaging, and primarily investigates lipids. This centre is located at the University of Gothenburg and Chalmers, with a node in Uppsala, and it is a world leader in neurobiology and medical research questions. The centre is currently more of a research network than an infrastructure. These platforms could benefit from being integrated with other infrastructures. A knowledge cluster is recommended within metabolomics, to guide potential users to technology and infrastructures suitable to the relevant question.

Systems biology uses mathematical models to explain experimental data, generate new hypotheses – which are then to be tested through experiments – and simulate experiments or treatments before they are implemented in real life. Models, simulations and predictions are expected to be some

of the most important tools for diagnosis and treatment of diseases, for the development of new treatment methods, for basic research in biology and for biotechnology and ecology. The need for access to expertise and tools will grow significantly in coming years.

The Swedish Research Council supports planning of the Systems Biology Infrastructure for the Life Sciences (SILS). There are common interfaces between bioinformatics and systems biology, and a likely development is for the systems biology support to be organised within an infrastructure for computational biology under the same umbrella, along with BILS and WABI. Dimensioning of the new organisation needs to be defined in connection with the 2015 application process. The field of computational biology is very close to e-Science and there is thus already a close collaboration with SNIC. The number of links between e-Science, bioinformatics and systems biology will keep increasing.



The three-dimensional structure of dihydropyrimidine dehydrogenase. Image: Centre of Cellular Imaging, Gothenburg. Courtesy of Doreen Dobritzsch and Gunter Schneider.

Recommendations 2015–2020

Reinforced interdisciplinary discussion and analysis

The infrastructures in the life sciences need to define their internal collaborations and maintain a continuous dialogue. A common view of development and academic goals could create enormous additional value to Swedish research. Collaboration between funding bodies which support national infrastructure also needs to be reinforced, and the lines between infrastructure and research must be clarified to ensure that resources are distributed in a transparent way and in the best interests of research.

Renewal, development and decommissioning of infrastructures should be supported

Since the technological development and research needs for infrastructure are dynamic and depend on global developments, the infrastructures being constructed must be designed to take into consideration and keep up with this development. This involves continuously adding nodes with new profiles and dismantling nodes that are no longer in demand within national infrastructures. It is also a matter of deliberately weighing up when national investments are motivated and times when it would be preferable to utilise international infrastructures. The systems propelling this development and the roles of various stakeholders within such a process must be clear. Principles for access to infrastructure for biological and medical research and how its use is to be funded also need to be developed. The universities need effective strategies when it comes to the funding of local (non-national) equipment to ensure externally funded basic research of a high quality.

The importance of infrastructure for hypothesis and concept-based research is increasing within the life sciences. Access to these infrastructures, which in many cases constitute new investments, may be decisive for researchers from all over the country to be able to conduct cutting-edge research, and these opportunities need to be communicated and highlighted in a better way, to benefit the research community in the best way possible. Some of the information needs to be formulated as education – especially at the graduate level – in what the infrastructures have to offer and how researchers can utilise these resources. The possible benefits for individual research groups created by infrastructure initiatives need to be communicated more clearly than has been the case so far.

This cultural shift has consequences at various levels: research planning in applications, budgeting, assessment of research applications, education and training. The Swedish Research Council, together with universities and major infrastructures, are all important stakeholders in the new research landscape.

Reinforced Swedish involvement in Europe

Sweden's involvement in international collaborations needs to be reinforced through the establishment of a transparent and effective process for situational analysis. Some of the collaborations created through ESFRI are potentially very valuable in providing Swedish researchers with necessary tools, new contacts and networks, without Sweden needing to invest large national resources. It is important to choose what contexts to participate in, and to have continuous information and Swedish influence when it comes to these.

Continued efforts to achieve a national coordination of biobanks and registers

The development towards a clear structure in which various national stakeholders collect, manage and distribute biological samples and data must continue. When it comes to biobanks, there is a national coordination of systems for biobank management (samples and data) between the health services and research sector.

A great future challenge is the connection and integration of various types of data: to connect patient data to genetic and molecular data from basic research in order to develop diagnoses, prevention and treatments within the field of personalised medicine. This falls somewhere in-between e-Science, bioinformatics and systems biology. The different stakeholders need to find ways to collaborate in a structured manner and in the long term. This also required integrity-assured technical, ethical and legal solutions. In this regard, there is a clear connection to infrastructures in the form of databases and registers for all public health and social sciences, as well as the general future structure of e-infrastructure (e-Science).

The use of MAX IV, XFEL and ESS within the life sciences

The large facilities for synchrotron light, free-electron lasers and neutron scattering-based research that Sweden is currently investing in are of great significance for future life science research. There are already user groups, for example within structural biology, that are completely dependent on

these tools, and the potential for new types of use should be utilised to the full. This will require new commitments, advanced technical support and training initiatives, both at the facilities in question and at the country's higher education institutions, to provide Swedish researchers with the information and contacts needed to continue developing their use of these technologies.

Coordination of equipment and expertise for research on animal models

Continued efforts for an increased national coordination within the field of animal modelling and phenotyping of animal models will be important. A general overview of the resources that have been constructed in Sweden so far is needed, as well as more knowledge of how a national coordination could add to the value of these. Access to an infrastructure for the phenotyping of mice and for the storage and distribution of genetically modified mouse strains could, for example, streamline and concentrate efforts within this area. Swedish membership in the European infrastructure Intrafrontier should be considered. Other animal models are also important within medical research. Sweden needs to support and develop a national coordination within animal models, so that important resources and new knowledge are made available to the health services.

Significant increase in support for e-infrastructure and life sciences

The rapid growth of data produced within the life sciences, along with the integrity issues associated with personal data that need to be dealt with, entails requirements for new technical solutions and resources, so that the management of data does not become a bottleneck, but a visible and prioritised part of the research landscape instead. A well-functioning system – which involves all the necessary parts, such as connected and accessible databases, the appropriate skills, a clear legislation for the processing of personal data etc. – entails a shared responsibility. This shared responsibility concerns the research-supporting infrastructures, the funding bodies, the legislators, the people setting the research framework as well as the researchers and institutions that use the infrastructures.

E-SCIENCE

Description of the field

E-science is a concept that builds upon the use of hardware (computers and network) and software as well as on human expertise, to enable scientific discovery. E-science methods are based on computation and exploration of data from various sources, such as simulations, experimental data and existing databases. The field has, to a large extent, emerged from the traditional high-end computing and data analysis communities, but is now rapidly spreading to all fields of science, medicine and engineering, including also social science, humanities and even the arts. As e-Science becomes a pre-requisite for other scientific fields this is likely to re-shape the way science is done. One example of this is that techniques for simulation and visualization are now sought after in new disciplines. Another example is the all-encompassing shift towards data-intensive and data-driven research, which was further explored in the recent report "Swedish science cases for e-infrastructures[25]".

The importance of e-Science has to some extent been recognized on a political level and when the government provided dedicated funding for a number of strategic research areas in 2008, e-Science was one of these areas. This resulted in funding of two new e-Science collaborations: eSSENCE and SeRC. Additional initiatives in e-Science are found at higher education institutions that are not part of eSSENCE and SeRC, and many researchers are using e-Science tools without labelling them as such.

In a wider definition it is recognized that e-Science does not necessarily depend on access to large-scale resources, thus it is important to be inclusive in the definition of e-Science activities. High quality science can be conducted on a range of both small and large digital platforms, and frequently exploits different levels during different project phases of a research project. Here we attempt to be inclusive of different kinds of users, usage and needs. There is however a bias towards users who need very large computing resources and associated services. This is motivated by the notion that these are still the dominating users of e-infrastructures today.

The computer networks, computing resources, and scientific databases necessary for e-Science comprise a special group of research infrastructures. Collectively, these are often referred to as electronic infrastructures or

25 *Science cases for e-infrastructures*, A. Ynnerman et al, Vetenskapsrådet 2014, ISBN: 978-91-7307-240-3.

e-infrastructures. An e-infrastructure is, in the context of this guide, thus taken to mean an infrastructure containing nationally available:

- digitally-based technology (hardware and software),
- resources (data, services, digital libraries),
- communications (protocols, access rights and networks),
- people and organizational structures needed to support modern, internationally leading collaborative research in all scientific fields, and
- the combination and interworking of all of these, as well as facilitating access to unique resources and services in other national or international e-infrastructures.

Note that this definition of e-infrastructure also includes the human expertise (in this report referred to as *advance user support provided by e-Science experts*) required to enable and support research efforts and to operate, maintain and evolve the hardware and software systems including any adaptation required by the research communities.

Users of e-infrastructures span from individual researchers to research projects and research infrastructures, thus requiring a diversity of resources. In principle, e-infrastructures are used in all scientific fields and are a prerequisite both for many research projects and for effective operation of other research infrastructures. E-infrastructures may not be as visible as large experimental research infrastructures but e-infrastructures are nevertheless a fundamental cornerstone of the research system as they provide the necessary means for improving both the broad base and the cutting-edge of Swedish research.

Infrastructure supported by the Swedish Research Council

EGI

The European Grid Infrastructure (EGI) aims to support pan-European research infrastructures and research communities with global e-infrastructures, the organizations has so far focused mainly on the high-energy physics field.

SNIC represents the Swedish Research Council in EGI and is a partner in EGI-coordinated EU-projects.

EUDAT

EUDAT is an EU-project that aims to build a collaborative data infrastructure to help researchers and communities across Europe with management and sharing of data. SNIC is the Swedish participant in EUDAT.

NeIC

The Nordic e-infrastructure Collaboration (NeIC) is a joint initiative between the Nordic countries to facilitate development of e-infrastructure solutions for Nordic research communities. NeIC was established in 2012 and is organizationally part of Nordforsk.

The collaboration started already in 2003 as the Nordic Data Grid Facility (NDGF) pilot project, which resulted in the innovation and successful deployment of the first and only distributed Tier-1 service within the WLCG collaboration. In later years the scope of the collaboration has been gradually enlarged to encompass a broader range of scientific fields. A core activity of the NeIC is to continue the successful Nordic Tier-1 activity. In addition, NeIC will focus on facilitating new joint e-infrastructure solutions for other Nordic research communities for which collective e-infrastructure solutions are a key to success. So far, NeIC has launched activities in two new fields, bio- and medical sciences and generic services in e-infrastructure.

NeIC is financed by Nordforsk and the five Nordic countries through The Swedish Research Council, The Research Council of Norway, Academy of Finland, Danish e-infrastructure Cooperation (DeIC) and The Icelandic University Research Network (RHnet).

NORDUnet

NORDUnet is a joint collaboration by the five Nordic national research and education networks (NRENs) in Norway (UNINETT), Denmark (DeiC), Finland (Funet), Iceland (RHnet) and Sweden (SUNET). NORDUnet operates a world-class Nordic and international network and e-infrastructure service for the Nordic research and educational community.

By collaborating through NORDUnet, the Nordic NRENs achieve cost-effective international connections, as well as increased influence on the development of international network topology and technical platforms.

NORDUnet monitors international network research activities and development projects and coordinates Nordic involvement in these projects, such as the GÉANT3 project. NORDUnet also act as the Nordic representative towards DANTE (Delivery of Advanced Network Technology to Europe), the organization operating GÉANT3 and other European network projects.

NORDUnet is the result of a Nordic collaboration financed by the Nordic Council in the 1980s. The collaboration was formalized in 1989, and NORDUnet was established as a limited company in 1995.

PRACE

PRACE (Partnership for Advanced Computing in Europe) aims to enable high impact scientific discovery, engineering research and development across all disciplines. PRACE seeks to realize this mission by offering world class computing and data management resources and services, with a long term goal of enhancing European competitiveness. To this end, PRACE also seeks to strengthen the European users of high-performance computing (HPC) in industry through various initiatives. All PRACE resources are allocated to users through a peer review process.

PRACE is established as an international not-for-profit association (aisbl) with 25 member countries and its seat in Brussels. The computer systems accessible through PRACE are provided by four large members (BSC representing Spain, CINECA representing Italy, GCS representing Germany and GENCI representing France) who have committed a total funding of 400 million euro for the initial PRACE systems and operations. The Swedish membership in PRACE implies that Swedish scientists are eligible to apply for access to these systems. The current funding period for PRACE ends in 2015 and there is presently intense discussion on the European level on how to continue the collaboration.

SNIC is the Swedish partner in PRACE, and as such SNIC has initiated a support services that assists Swedish research groups in utilizing the massively parallel PRACE computers.

SNIC

National HPC resources and data storage for academic research in Sweden is provided by The Swedish National Infrastructure for Computing (SNIC). The head office, responsible for the strategy and budget, is hosted by Uppsala University and coordinates resources and services delivered by six computing centers at major Swedish universities. From north to south the centers are HPC2N at Umeå University, UPPMAX at Uppsala University, PDC at Royal

Institute of Technology, NSC at Linköping University, C3SE at Chalmers University of Technology, and Lunarc at Lund University.

The HPC-resources available through SNIC cover a full range of facilities, from what have traditionally been called supercomputers to commodity clusters with standard interconnects. Nationally accessible storage resources are provided through the Swestore project. Swestore is used for short and medium-term storage for research projects, and also for making data available to others either publicly or under agreed access restrictions. Most demands are coming from climate, environment and life sciences, and high-energy physics (through WLCG). Research projects applying for computer time and storage resources are evaluated on scientific merits and technical feasibility.

In addition to hardware resources, SNIC also coordinates support functions provided by e-Science experts. They generally provide expert knowledge and support in relation to the SNIC-hardware and cover a wide range of scientific fields, including a specific action for supporting researchers that use PRACE resources.

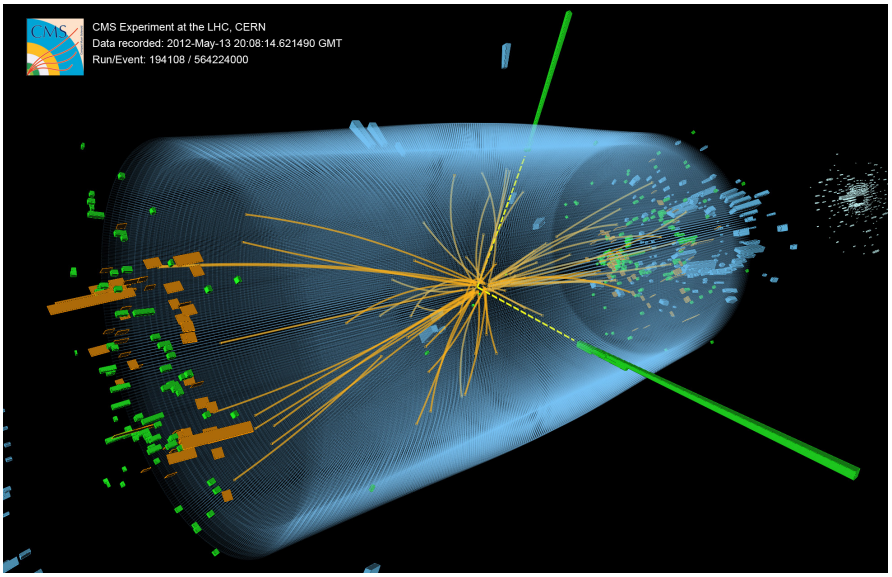
SUNET

Networking is one of the key components of the e-infrastructure landscape. SUNET (The Swedish University Network) serves the affiliated higher education institutions and a number of other organizations by providing an infrastructure for national and international data communications together with a variety of data services. SUNET (founded in the 1980's) is the facility through which Swedish researchers access international and other national e-infrastructures and their associated resources and services. It is also the facility through which various forms of electronic collaboration, such as videoconferencing, take place.

The current implementation of SUNET is named OptoSUNET and delivers redundant and diverse connections at 10 Gbps to all major Swedish higher education institutions. OptoSUNET is also well connected to international networks and provides Swedish researchers with access to international collaborations. In addition to normal network access with routers, OptoSUNET can provide point-to-point connections to transmit large amounts of data directly between two points through a wavelength service. This service is of increasing importance to large e-Science projects and research infrastructures.

SUNET is hosted by The Swedish Research Council since 2001 and has a financial model that differs from all other research infrastructures. The

Swedish Research Council receives ear-marked funding for SUNET from the Ministry of education, and SUNET also has its own instruction.



Data from the CMS experiment at CERN. Image: © 2013 CERN, for the benefit of the CMS Collaboration. Image credit: Thomas McCauley and Lucas Taylor.

WLCG

WLCG (The Worldwide LHC Computing Grid) is a distributed computing infrastructure that provides the production and analysis environments for the Large Hadron Collider (LHC) experiments at CERN. It is managed and operated by a worldwide collaboration between the experiments and the participating computer centres. The resources are distributed across the world for funding and sociological reasons. Currently, WLCG is made up of more than 170 computing centres in 36 countries that process, analyse and store data produced from the LHC, making it equally available to all partners regardless of their physical location.

The WLCG is now the world's largest computing grid and it is technically composed of four levels, or "Tiers", which are made up of the computer centres. The tiers are called Tier-0, Tier-1, Tier-2 and Tier-3, and between them these tier sites process, store and analyse all the LHC data. Tier-0 is the CERN computer centre, while Tier-1 centres are large computer centres holding a proportional share of raw and reconstructed data and with round-

the-clock support for the grid. Tier-2 are national and Tier-3 are regional or local computer centres. NeIC operates a common Nordic Tier-1 service, which is one of 12 Tier-1 centres.

Description of potential new infrastructure

Stronger integration between national e-Science communities and e-infrastructures

Sweden has a tradition of strong efforts on computing infrastructure and networks, and in the last few years additional e-infrastructures have emerged. There are also strong national e-Science communities where much of the development of tools and methods is currently done. Such e-Science communities would be natural partners for e-infrastructures, research infrastructures and researchers. The e-infrastructures and other e-Science activities together comprise a large range of activities, tools and services, which support a substantial and heterogeneous set of research communities with different requirements. The great challenge for the coming years will be to consolidate the many parallel e-Science efforts into coherent e-infrastructure that support a broad range of activities, over a wide range of scientific fields, and at the same time remains sufficiently agile. This calls for a common agenda and improved coordination between all parties, to ensure optimal development.

In light of the expected rapid changes, The Swedish Research Council invited professor Ynnerman[26] to provide guidance on future progress of the Swedish activities in e-Science and e-infrastructures. This has initiated a discussion on bringing all e-activities under a common umbrella to achieve a higher degree of both coordination and synergies between different e-activities. This idea is acknowledged here and it should be a long-term goal to strengthen the coordination between all e-activities. However, a new umbrella organization has to be anchored with the higher education institutions and this discussion should be part of the work with anchoring the new model for prioritization and funding of national research infrastructures. In this dialogue all e-infrastructures for network, storage, HPC-resources, databases and advanced user support should be included.

26 Presentation by A. Ynnerman for the board of the Swedish Research Council, dnr 811-2013-100

Strengths and weaknesses

e-infrastructure hardware components

Sweden has well-established national core e-Science infrastructure, including network, HPC and storage, which supports a range of scientific fields.

SUNET provides well-developed and effective national and international data communication through its network and services. The reliable connections form a necessary back-bone for research and education alike. SUNET is hosted by The Swedish Research Council and has a special instruction from the Ministry of Education, including ear-marked funding, which gives SUNET a uniquely strong position. A weakness is that the user-dialogue regarding development of services has sometimes been limited.

SNIC provides HPC-resources that generally appear strong in an international comparison, both in terms of hardware and technological competence. Short and midterm storage is provided by the Swestore project under SNIC, and the users are generally satisfied with this service. However, storage is threatening to become a bottle-neck due to the rapidly increasing data volumes. A current weakness is the lack of e-infrastructure to handle the rapidly increasing proportion of sensitive data of human origin. Production, analysis and storage of such data place additional requirements[27] on both equipment and operation. The establishment of a SNIC head-office in 2012 has led to an increased coordination between activities but this need to be strengthened further to ensure efficient resource usage and access for users.

There are also established or emerging national facilities for managing and sharing of data in some fields, including the social sciences (SND), climate and environmental sciences (ECDS), life sciences (BILS) and biodiversity sciences (GBIF, LifeWatch). It is however, a weakness that there is no coherent national e-infrastructure for data handling.

Coordination between e-infrastructures and other research infrastructures

National e-infrastructures have been successfully expanded in recent years and the individual e-infrastructure components are generally strong. However, a pronounced fragmentation and too little influence from the user communities on the services provided have hampered the e-infrastructures to reach their

27 *Assignment to SNIC regarding the inventory of the needs of other infrastructures for large-scale resources for computation and storage.* Vetenskapsrådet dnr 823-2014-7381.

full potential. The lack of coherent national e-infrastructure is problematic both for research infrastructures and researchers. A research infrastructure, or research project, that wishes to build a production environment with storage, user access and interfaces, and analysis facilities has to interact with several e-infrastructures. From a user point of view it would be much easier with a one-stop-shop for all services. This is also true on an international level.

Many experimental research infrastructures have significant needs for supporting e-infrastructure but there is no general practice in place for prioritizing these and e.g. SNIC struggles to prioritize between needs from projects and research infrastructures. This is a severe weakness since many research infrastructures depend heavily on e-infrastructures for their operation. This situation is a consequence of the current funding model for research infrastructures, where e-infrastructure needs are often briefly described in the proposals and not budgeted for properly. In addition to the e-infrastructure required for operation of research infrastructures, data produced by the research infrastructures usually result in new research that also requires supporting e-infrastructure.

Advanced user support provided by e-Science experts

E-Science experts provide expert knowledge in computing, programming, data analysis, algorithm development and visualization to other researchers. This type of advanced user support has great potential to strengthen Swedish research in all scientific fields. There is often a high technical threshold for new users to start using e-Science tools and e-infrastructures, which calls for strong effort not only on advanced user support, but also on training opportunities, development of user-friendly interfaces and online support.

Two broad types of advanced user support have emerged in recent years; generic e-Science experts that are focused on support close to the hardware and/or on general technologies, and domain specific e-Science experts who work closer to their respective research field. One apparent weakness today is the lack of coordination, and unclear division of responsibilities, between organizations providing advanced user support. E-Science experts may today be employed at e-infrastructures that provide either advanced user support (e.g. BILS and WABI) or hardware (SNIC), within the strategic research areas in e-Science, or in a research group. Further development of the advanced user support related to e-infrastructures would benefit from a discussion on the responsibilities of the respective parties. Another apparent problem is the lack of domain specific application experts in many

scientific fields.

A common concern for all types of e-Science experts that provide advanced user support is the lack of long term funding and attractive career paths. The e-Science experts are often not pursuing their own research but are instead key persons providing tools and knowledge that enable other researchers to do cutting-edge science. They are crucial for the research system and it is critical to keep them in science.

Educational gap – need for training of a new generation

Programming, computing and data analysis have long been integral parts of some scientific fields. With the advent of high-throughput experimental techniques in recent years, the use of e-Science tools has extended into new scientific communities. Furthermore, as sharing of research data is becoming norm in an increasing number of disciplines this calls for additional skills in management, curation and preservation of data. Management of research studies, including workflows, is another aspect which requires new skillsets.

This development calls for comprehensive efforts in education and training. E-Science experts will not, and should not, be able to provide support at all levels but should rather focus on advanced development and support. It is therefore equally important to provide adequate courses for researchers at all levels to close the educational gap that will otherwise prevent them from using e-Science tools and e-infrastructures. Higher education institutions have an important role as providers of courses for active researchers, as well as in educating the next generation of data-driven scientists. Although this is starting to happen, the slow adaption is a severe weakness of the research system today.

International presence

Swedish researchers have been successful in gaining access to European HPC- resources and in contributing to the construction of European and international e-infrastructures. This is a potential driver for national development, e.g. through knowledge transfer. Many emerging ESFRI-projects have clear e-infrastructure components and a focus on different aspects of data, which promises to strengthen Swedish research as they gain easier access to valuable data. However, a common concern is that Sweden is seldom leading the development in international collaborations but is rather an implementer. This way, dependence on international political processes may sometimes restrict the Swedish Research Council's ability to make an independent choice of which e-infrastructures and technologies to support nationally.

Support for generic tools and technical solutions

Little financial support exists today for generic technical solutions, such as access to popular technology stacks, server and storage solutions, online collaboration platforms, cloud computing resources and user-friendly interfaces. Similarly, there is a lack of support for development and maintenance of software and middleware. Swedish scientists have successfully developed new algorithms and methods based on research projects but there is little funding available for implementation of these algorithms in robust and easy-to-use software. This hampers researches and research infrastructures alike since development of software and/or middleware is an important part of many research projects and research infrastructures.

Essentially in all fields of science there is an imminent need to have a more rigorous and comprehensive approach to data storage. Tools for data storage, access and curation is another aspect which is not properly addressed today. When this basic service is in place there are potentially even greater challenges ahead with data discovery and exploration in shared research environments. There is again a lack of systematic funding instruments to do this today.

Trends and tendencies

Shift from simulation-driven research to data-driven and data-intensive research

Data-driven research may be described as the application of methods for data mining and machine learning algorithms over raw data to find patterns, and to detect correlations and causality relationships. Although this has been done for a long time the rapidly increasing volumes of data produced; e.g. by modern scientific instruments, high-performance simulations, sensor networks and digitized collections, are now propelling the development of data-intensive and data-driven research (sometimes also referred to as *big data* science) in new fields. With the availability of large datasets there is a parallel trend for interdisciplinary approaches where data from multiple sources is integrated to address new research topics, or old topics in new ways.

While the availability of large data collections opens new opportunities for scientific breakthroughs this also puts new demands on scientists and e-infrastructures. Scientists across various disciplines need to establish new research practices (with a correlated need for training and education), and

e-Science specialist need to develop new methods, algorithms and software tools. It is likely that interactive exploration of data will soon become an important part of the research practice. Hence, in addition to high performance batch processing, we observe an increased demand for scientific applications that allow for interactive access, analysis and visualization of data. Interactive software tools are more demanding in terms of latency and typically use special data organization and indexing methods, as provided by database management systems and search engines.

Similarly high-performance simulations are becoming increasingly data-intensive and for these simulations to reach their full potential the data needs to be integrated with high-quality tools for visualization.

Open access to research data and tools

In parallel with the trend for data-intensive and data-driven research there is an international movement towards open access to research data and tools. The European Commission has recognized this and emphasized the importance of sharing research data and tools in Horizon 2020, the new framework for research and innovation. A cornerstone for dissemination of data is secure long-term preservation, including curation and metadata declarations for the data. Similarly, for tools and software that are made openly available there is a need for proper documentation. With this in place the next layer includes infrastructures for dissemination, which requires both technical solutions and competence centres. Some examples of technical solutions needed are networks, databases, standard formats for data and metadata, methods and standards for authentication, authorization and identification of users and datasets.

The Swedish Research Council has been asked to propose national guidelines for open access, and has published a separate report on this.[28]

Development of hardware and software

The rapid development of the performance of computing chips seems to continue approximately according to Moore's law, which states that the number of transistors on a chip increases exponentially and doubles approximately every 18th month. The reason for this is a combination of increased R&D investments and improved manufacturing technologies. The same factors also a driver for increased costs and complexity for HPC systems, and

28 *Proposal for National Guidelines for Open Access to Scientific Information.* Vetenskapsrådet 2015, ISBN: 978-91-7307-263-2.

therefore increased funding (above inflation adjusted scale ups) is needed to just follow the development curve. To fully take advantage of new hardware configurations further efforts to re-engineer software (including code optimization, development of algorithms and memory management) are needed. Another crucial part is training. All these factors will contribute to the increasing costs for HPC resources.

Development of algorithms, methodologies and tools is needed also because of the rapid increase of diverse data. Not only the size of the data collections is a burden but more often the complexity of the data itself poses challenges towards discovery and insights. Thus novel algorithms, methodologies and tools need to be developed and deployed. HPC-centres could play a role in this by providing access to small scale research clusters with advanced hardware for developmental work. Furthermore, a closer connection between mathematical and statistical sciences and the application domains would also be beneficial.

This trend does not only concern the development of hardware and software for different scientific fields, but also engineering research about e-infrastructures and e-Science tools. Some examples include development of methods and frameworks for software development, as well as development of hardware for HPC, cloud services and digital communication.

Rapidly increasing needs from other research infrastructures

As more and more research infrastructures are generating large volumes of data their demands for storage and compute resources are rapidly increasing. Research infrastructures represent a distinctly different user group from research project, which have traditionally been the main users of SNIC-resources. As opposed to research projects, which are allocated resources in competition through an allocation committee, some research infrastructures are dependent on continuous guaranteed access to storage and HPC-resources for their operation and collection of data from experiments. Two such examples are LHC, which is completely dependent on WLCG, and NGI which relies on the SNIC center UPPMAX. As other large research infrastructures (e.g. XFEL and Max IV) become operational a similar development is likely to be seen for them. Some research infrastructures may also pose additional demands in terms of requirement for interactive access to HPC-resources, a service which is currently not supported by SNIC.

Having HPC and storage resources closely linked to the research infrastructures offers several advantages to the research infrastructure, in terms of management and planning for usage, upgrades and costs. The last

point is especially important as several existing and new research infrastructures are becoming large consumers of e-infrastructure resources. If this trend continues it is severely threatening to decrease the resources available for other users, such as research projects and communities.

Increasing demand for advanced user support

There is an increasing demand for advanced user support from e-Science experts (synonyms that are often used are *application experts*, *research engineers* and sometimes *the human e-infrastructure*) within nearly all scientific fields. The needs are diverse but tend to fall into the following categories:

(a) services close to the operating systems of hardware, e.g. installation of software on HPC-clusters or setting up networks.

(b) services that address the need for support with systems software, e.g. compilers, databases and web-services. Skills range from helping with programming and designing/setting up a database, but can also be advanced tasks like adaption/optimization of code for different platforms.

(c) application oriented support, directed at specific tools and/or user communities.

The first two (a and b) are commonly referred to as *generic* user support since they tend to serve several disciplines and generally do not require knowledge in a specific scientific field. The latter (c) is often referred to as *domain specific* user support and these experts tend to work closer to the research communities and therefor require knowledge of their specific scientific field. We observe that the practices on what advanced user support is, and *who* funds it varies to some extent between scientific fields.

Internationalization

Utilization of international resources becomes increasingly important in many scientific fields. One example is PRACE which offers advanced HPC-resources that are not available through the national HPC-provider SNIC. Another example is SUNET which provides reliable and fast network to Swedish universities, researchers and research infrastructures through collaboration with international partners. ESFRI-projects are a third example. A third example are ESFRI-projects, where a majority have an e-infrastructure

component which give researchers access to e.g. data, services and tools that may not be available elsewhere. As utilization of international resources becomes more prominent it is important that the trend is accompanied by corresponding national support to allow researchers to make the most of the international e-infrastructures.

Recommendations 2015-2020

As data-driven research is becoming more prominent and widely adopted in across various scientific fields the e-infrastructures and e-Science communities will face a number of challenges, including:

- rapidly increasing needs from established, and planned, research infrastructures,
- increased, and possibly also new, needs from existing user communities,
- inclusion of new user communities with little tradition of using e-infrastructures,
- the number of e-Science experts with the required expertise, skills and interests seem to become a bottleneck, thus there is a need to maximize throughput and pool resources and expertise.
- internationalization of resource usage and globalization of research communities poses specific challenges in terms of coordination and allocation of expertise and hardware.

To accommodate these, and additional, challenges strong action is needed and the following actions are recommended.

Stronger integration between national e-Science communities and e-infrastructures

To allow researchers to take full advantage of existing e-infrastructures and e-Science communities it is necessary to consolidate the fragmented activities into more coherent and easily accessible structures. This development should be done in close dialogue with higher education institutions and user communities. It is imperative that the evolution of services provided is driven

by the needs of the users, i.e. researchers and research infrastructures.

The Swedish Research Council intends to promote further coordination between e-infrastructures and e-Science communities, especially activities financed by the council. The new model for prioritization and funding of research infrastructures of national interest is an instrument to achieve more coherent, easily accessible and cost-efficient national e-infrastructure.

Securing adequate access to networks, storage, computing resources, advanced user support, e-Science tools and databases

The need for high quality e-infrastructures and advanced user support is increasing rapidly and will continue to do so until 2020 (and beyond). Increased base level funding for networks, storage and computing resources is needed just to keep up with the global technical development. To reach further and achieve the scientific breakthroughs described in the report "Swedish science cases for e-infrastructures[29]" it is necessary to provide additional directed funding. The base funding for networks, HPC resources and storage needs to increase to ensure that the national e-infrastructures are be able to continue the established and well-functioning services to existing and new users, such as individual researchers and research infrastructures. In addition, The Swedish Research Council and others need to make a political decision on if additional directed funding to e-infrastructures should be provided to further promote high-quality research.

Continued scientific exploitation of e-infrastructures and data from experimental research infrastructures require a strong effort on advanced user support, including both generic and domain specific e-Science experts. Higher education institutions, research infrastructures and the Swedish Research Council need to provide substantially larger funding to meet the rapidly increasing need for advanced user support. All stakeholders also need to acknowledge the need to develop attractive career paths for e-Science experts providing advanced user support.

Continuous development and maintenance of high quality e-Science tools and community software is crucial for scientists and research infrastructures to stay competitive. Funding instruments are needed to enable both elevating generic high quality tools form a research group to community software, and to include development of necessary software/middleware in the overall plan and budget for building and operating research infrastructures. This

29 Report from the Swedish Research Council, by Anders Ynnerman et al, 2014. ISBN: 978-91-7307-240-3.

is lacking today and needs to be addressed by funders. As research infrastructures often depend on specific software/midleware for their operation the development of such software/middleware should be included in, and budgeted for, the application for infrastructure grants.

It is recognized elsewhere in the guide that improved coordination of databases in medicine and social sciences is highly desirable. To achieve this it will be important to develop federated databases that allow researchers to share and access distributed databases in a secure manner, preferably through a common interface.

Developing a sustainable funding model that secures adequate access to e-infrastructure for research infrastructures and large research projects

Supporting e-infrastructure such as HPC and storage are quickly becoming integral parts of the operation of many research infrastructures. It is therefore urgent to develop a sustainable funding model to ensure that: (1) research infrastructures with high national priority have access to the supporting e-infrastructure needed for their operation, (2) research infrastructures interact closely with the e-infrastructures throughout their planning and operational phases and (3) the cost for supporting e-infrastructure is included in the overall budget for research infrastructures. In this way the full costs for supporting e-infrastructure can be accounted for in the prioritization process prior to a funding decision of an experimental research infrastructure.

The research infrastructures should usually avoid developing their own e-infrastructure but rather use existing ones (such as SNIC and SUNET), or commercial providers. When existing e-infrastructures are used these should receive dedicated funding to meet the needs from the research infrastructure. As far as possible, the e-infrastructures should try to avoid dedicated solutions for research infrastructures since these will often be less cost-effective than general ones. If purpose-built resources are nevertheless needed these should still be part of the existing e-infrastructure (e.g. compute resources at SNIC).

To ensure that research infrastructures get access to the supporting e-infrastructure needed for their operation also in the future, and that the appropriate funds are made available for this, it is imperative that all applications for infrastructure grants include a proper description and budget for the supporting e-infrastructure.

The proposed model is focused on research infrastructures but we see that similar issues are also relevant for large research projects. The funding streams are less evident in this case and this should be further explored.

Advancing the skills and awareness of the research community – educating and training the e-Science generation

E-Science is changing the current research practices and the development is placing increasingly higher demands on individual researchers, research communities and infrastructures to become proficient in computing, programming and databases etc. To achieve this, and to support the rapid development of data-intensive and data-driven research, it is crucial that higher education institutions work pro-actively and offer courses at all educational levels. Another important effort would be to initiate an interdisciplinary graduate school in e-Science.

Table 2. National and international infrastructure receiving grants from the Swedish Research Council in 2014 (the Council for Research Infrastructures, RFI)

This is a presentation of the infrastructures currently funded by the Swedish Research Council (grants allocations in 2014). The infrastructures are presented by subject area, based on the subject area review in which they are described. However, it can be noted that several infrastructures are used within more than one subject area.

Infrastructure *Including Swedish nodes/ experiments*	**National (Nat)/ International (Int)**	**URL**	**Distributed (D)/ Centralised (C)/ Virtual (V)**	**Status**
Materials Science				
ESRF, synchrotron light	Int	http://www.esrf.eu/	C	Convention-bound Sweden is a member through a Nordic consortium (Nordsync)
ESS, spallation source	Int (ESFRI)	http://europeanspallationsource.se/	C	Sweden is host. Construction begins in 2014 Planned operational launch in 2019
XFEL, X-ray free-electron laser	Int (ESFRI)	http://www.xfel.eu/	C	Convention-bound, estimated operational launch in 2017
ILL, spallation source *SuperAdam, neutron reflectometer at ILL*	Int/Nat	http://www.ill.eu/	C	Membership via TRANSI collaboration *Instrument operational, operational grant until 2015*
ISIS, spallation source *Polaris and HRPD, diffractometers at ISIS*	Int	http://www.isis.stfc.ac.uk/	C	Membership (until 2019) *CRG instrument Polaris is operational – HRPD under construction, operational grant until 2017*

Infrastructure *Including Swedish nodes/ experiments*	**National (Nat)/ International (Int)**	**URL**	**Distributed (D)/ Centralised (C)/ Virtual (V)**	**Status**
MAX IV, synchrotron light	Nat	https://www.maxlab.lu.se/	C	Estimated operational launch in 2016. Operational grant until 2018
Myfab, materials research cleanroom. *MC2 Nanofabrication Laboratory*, Chalmers. *Electrumlab, KTH. The Ångström Microstructure Laboratory, UU*	Nat	http://www.myfab.se/	D	Operational grant until 2015
UU				
PETRA III – hard X-ray synchrotron *SMS (Swedish Material Science) beamline*	Int	http://petraiii.desy.de/	C	Under construction, operational launch planned in 2016/17
Physics and Engineering Sciences				
CERN, particle physics. *Experiments with Swedish participation: ATLAS/ALICE, CTF3, Isolde*	Int	http://home.web.cern.ch/	C	Convention-bound Operational phase. Major upgrades 2018–2019.
DESIREE, ion physics	Nat	http://www.atom.fysik.su.se/index.php/research/experimental-group/desiree	C	Operational grant until 2015
ESO, astronomy	Int	http://www.eso.org/public/	C	Convention-bound Operational phase. Construction of E-ELT from 2015 and on.
FAIR, nuclear physics	Int (ESFRI)	http://www.fair-center.eu/public.html	C	Convention-bound Operational launch in 2020
IceCube, neutrino telescope	Int	http://icecube.wisc.edu/	C	Operational phase

Infrastructure *Including Swedish nodes/ experiments*	**National (Nat)/ International (Int)**	**URL**	**Distributed (D)/ Centralised (C)/ Virtual (V)**	**Status**
ISF, solar telescope	Nat	http://www.solarphysics.kva.se/	C	Operational grant until 2017
NOT, astronomy	Int	http://www.not.iac.es/	C	Phased out 2015–2019
JIVE-ERIC, radio astronomy	Int	http://www.jive.nl/	D	Operational phase. Negotiations in 2015 after the establishment as an ERIC.
Onsala Space Observatory, radio astronomy and geodesy	Nat	http://www.chalmers.se/sv/centrum/oso/Sidor/default.aspxChalmers	C	Operational grant until 2015
Energy Research				
ITER and EUROfusion, fusion reactor	Int	http://www.iter.org/ https://www.euro-fusion.org/	C	Funded via Euratom
Environmental sciences – Planet Earth				
Buoy-based environmental measuring system. *Mobile units coordinated by SMHI*	Nat	http://www.smhi.se/kunskapsbanken/oceanografi/havsbojar-1.13442	D	Grants for expensive equipment until 2016
Drilling, solid earth studies Coordinated by UU. *Riksriggen (LTH, LTU), IODP (Washington) ICDP (Potsdam)*	Nat/Int	http://www.riksriggen.se/www/ http://www.iodp.org/ http://www.icdp-online.org/home/	D	Operational grant until 2017
ECDS, environmental and climate data	Nat	http://www.smhi.se/ecds	V	Operational grant until 2015
EISCAT (EISCAT 3D) ionosphere research. *Three radar systems coordinated from Kiruna*	Int (ESFRI)	https://www.eiscat.se/	D	Negotiations regarding different countris co-financing of EISCAT 3D are underway

Infrastructure *Including Swedish nodes/ experiments*	**National (Nat)/ International (Int)**	**URL**	**Distributed (D)/ Centralised (C)/ Virtual (V)**	**Status**
GBIF and LifeWatch (SLW), biodiversity informatics	Nat/Int	http://www.gbif.org/ http://www.gbif.se/ http://www.svenskalife-watch.se/en/	V	Operational grant until 2015. Joint application for continuation grant
GET – geodata for research, education and culture	Nat	https://www.geodata.se/sv/Ga-med/Forskning-utbildning-och-kultur-verksamhet/	V	Grants for large databases until 2016
ICOS, carbon dioxide measurements. *Centre for Environmental and Climate Research (CEC) , LU* *Department of Geological Sciences , SU* *Abisko Scientific Research Station , Polarforsknings-sekretariatet* *Department of Forest Ecology and Management , SLU* *Department of Plant and Environmental Sciences , GU* *Department of Earth Sciences , UU*	Nat/Int (ESFRI)	www.icos-sweden.se/ http://www.icos-infra-structure.eu/	D	Operational grant until 2016
Nordsim and Vega, analysis instruments for earth sciences	Int (nordisk)/Nat	http://www.nrm.se/english/researchandcollections/geosciences/nordsim.904_en.html http://www.nrm.se/english/researchandcollections/geosciences/vegacenter.8999657_en.html	C	Operational grant until 2016. Joint application for continuation grant

Infrastructure *Including Swedish nodes/ experiments*	**National (Nat)/ International (Int)**	**URL**	**Distributed (D)/ Centralised (C)/ Virtual (V)**	**Status**
Resdacs, Database of earth observations for climate research (atmospheric data from the Odin satellite)	Nat	http://odin.rss.chalmers.se/	V	Grants for large databases until 2014
SITES, environmental measuring stations *Abisko Scientific Research Station* *Asa research station* *Erken laboratory* *Grimsö Research Station* *Lönnstorp Research Station* *Röbäcksdalen Research Station* *Skogaryd Research Station* *Svartberget Research Station* *Tarfala Research Station*	Nat	http://www.fieldsites.se/	D	Operational grant until 2017. Evaluation in 2015.
Humanity, culture and society				
ANDIS and ANDIU (all new diabetics in Scania and Uppsala counties)	Nat	http://andis.ludc.med.lu.se/ http://www.andiu.se/	V	Operational grant until 2015
Betula Project – longitudinal project on ageing and memory	Nat	http://www.betula.su.se/	V	Operational grant until 2015
CESSDA – Consortium of European Social Science Data Archives AS	Int (ESFRI)	http://www.cessda.net/	V	Operational phase
SWE-CLARIN/CLARIN – Common language resources and technology infrastructure	Nat/ Int (ESFRI)	http://clarin.eu/ http://spraakbanken.gu.se/swe/Forskning/Infrastruktur/swe-clarin	V	Operational grant until 2018.
DASISH – Data Service Infrastructure for the Social Sciences and Humanities (ESFRI).	Int	http://dasish.eu/	V	Operational phase. Coordinated by SND

Infrastructure *Including Swedish nodes/ experiments*	**National (Nat)/ International (Int)**	**URL**	**Distributed (D)/ Centralised (C)/ Virtual (V)**	**Status**
DDB – the Demographic Data Base	Nat	http://www.ddb.umu.se/english/	V	Grants for large databases until 2015
The Drama Web – humanities infrastructure	Nat	http://www.dramaweb-ben.se/	V	Operational grant until 2014
EIRA database – on chronic inflammatory diseases	Nat	http://www.eirasweden.se/index1.htm	V	Grants for large databases until 2015
ESS – ERIC, European Social Survey	Nat/Int (ESFRI)	http://www.europeansocialsurvey.org/	V	Operational grant until 2016
EUI (European University Institute)	Int	http://www.eui.eu/Home.aspx	C (Institut)	Operational phase
ISSP – International Social Survey Program	Nat	http://www.issp.org/	V	Grants for large databases until 2015
LNU – the Swedish level of living surveys	Nat	http://www.sofi.su.se/forskning/tre-forskning-savdelningar/lnu	V	Operational grant until 2014
Malmö population database	Nat	http://swecris.se/converis/publicweb/Project/44158?share=false&cntpers=false&reqstfulltxt=false&reports=false&lang=1	V	Operational grant until 2015
National In-depth Road Accident Database	Nat	http://www.chalmers.se/sv/projekt/Sidor/Nationell-djupstudiedatabas-f%C3%B6r-trafikolyckor.aspx	V	Grants for large databases until 2014

Infrastructure *Including Swedish nodes/ experiments*	**National (Nat)/ International (Int)**	**URL**	**Distributed (D)/ Centralised (C)/ Virtual (V)**	**Status**
PCBaSe (Swedish prostate cancer database)	Nat	http://www.cancercentrum.se/uppsalaorebro/forskning/registerstudier/pcbase-sweden/	V	Grants for large databases until 2015
Population Studies of Elderly in Gothenburg	Nat	http:/www.epinep.gu.se	V	Grants for large databases until 2015
SATSA – Swedish Adoption/Twin Study of Ageing	Nat	http://ki.se/en/meb/satsa-the-swedish-adoptiontwin-study-of-aging	V	Grants for large databases until 2014
SEDD – the Scanian Economic Demographic Database	Nat	http://www.ed.lu.se/databases/sedd	V	Grants for large databases until 2015
SHARE – Survey of Health, Ageing and Retirement in Europe	Nat/Int (ESFRI)	http://www.share-project.org/	V	Operational grant until 2017
SHFA – the Swedish Rock Art Research Archives	Nat	http://www.shfa.se/	V	Operational grant until 2015
SLOSH – The Swedish Longitudinal Occupational Survey of Health	Nat	http://www.idear-net.net/slosh/	V	Grants for large databases until 2015 and operational grant until 2018
SMC – the Swedish Mammography Cohort	Nat	http://snd.gu.se/sv/catalogue/study/618	V	Operational grant until 2015
SNAC-K – ageing and care	Nat	http://www.snac-k.se/indexsv.htm	V	Operational grant until 2015
SND data service for social sciences, humanities and medicine	Nat	http://snd.gu.se/	V	Operational grant until 2015

Infrastructure *Including Swedish nodes/ experiments*	**National (Nat)/ International (Int)**	**URL**	**Distributed (D)/ Centralised (C)/ Virtual (V)**	**Status**
SweCens – national censuses	Nat	https://riksarkivet.se/swecens	V	Grants for large databases until 2015
UCDP – Uppsala Conflict Database Program	Nat	http://www.ucdp.uu.se/gpdatabase/search.php	V	Operational grant until 2015 Grants for large databases until 2015
ETF – Evaluation Through Follow-up	Nat	http://ips.gu.se/forskning/forskningsprojekt/ugu	V	Operational grant until 2015
Life Sciences				
BBMRI.se/BBMRI-ERIC biobanks *Biobanks at GU, KI, LiU, LU, UmU, UU, Örebro University*	Nat/Int (ESFRI)	http://www.bbmri.se/ http://bbmri-eric.eu/	D	Operational grant until 2015
BILS/ELIXIR, bioinformatics *Staff at Chalmers, GU, KTH, KI, LiU, LU, NRM, SLU, SU, UmU, UU*	Nat/Int (ESFRI)	https://www.bils.se/ http://www.elixir-europe.org/	D	Operational grant until 2015
CBCS, chemical biology *The Laboratories for Chemical Biology, KI* *The Laboratories for Chemical Biology, Umeå* *Uppsala university drug optimization and pharmaceutical profiling platform*	Nat	http://www.cbcs.se/	D	Operational grant until 2015
CyTOF, cellular visualisation	Nat	http://www.hu.liu.se/cf/cytof?l=sv	C	Grants for valuable equipment until 2017
EMBL, molecular biology	Int	http://www.embl.de/	D	Operational phase

Infrastructure *Including Swedish nodes/ experiments*	**National (Nat)/ International (Int)**	**URL**	**Distributed (D)/ Centralised (C)/ Virtual (V)**	**Status**
INCF, neuroinformatics	Int	http://www.incf.org/	D	Operational phase
MIMS, molecular biology	Nat	http://www.mims.umu.se/	C	Operational grant until 2016
NGI, sequencing and genotyping *Sequencing KTH, SciLifeLab, Sequencing and genotyping, UU, SciLifeLab*	Nat	http://www.scilifelab.se/platforms/ngi/	D	Operational grant until 2015
SCAPIS, cardiopulmonary research *Nodes at the university hospitals of Göteborg, Linköping, Malmö, Stockholm and Uppsala*	Nat	http://www.hjart-lung-fonden.se/scapis	D	Operational grant until 2015. Grants for expensive equipment until 2018
Swedish bioimaging, biological and medical imaging *Superresolution microscopy (3D-STED, 3D-SIM and 3D-PALM), SciLIfeLab Stockholm* *Superresolution Microscopy (SIM/PALM), Center for Cellular Imaging, GU* *Magnetoencephalography (MEG), KI* *Superresolution microscopy (STORM, TIRF, 4D-Confocal), Biochemical Imaging Centre Umeå* *Field Emission Scanning Electron Microscopy (FESEM), UmU* *7T MRI, LU* *PET/MR, UU* *NanoPET-CT, UU*	Nat	http://www.bioimaging.se/	D	Operational grant until 2015. Several different grants for expensive equipment. Joint application in 2015.

Infrastructure *Including Swedish nodes/ experiments*	**National (Nat)/ International (Int)**	**URL**	**Distributed (D)/ Centralised (C)/ Virtual (V)**	**Status**
Swedstruct/INSTRUCT structural biology *Protein production, KI* *Macromolecular crystallography, MAX IV* *Swedish NMR centre*	Nat/Int (ESFRI)	https://www.structuralbiology.eu/	D	Operational grant until 2016 Transition to ERIC is being planned.
e-Science				
NeIC, Nordic collaboration for common e-infrastructure	Int	http://neic.nordforsk.org/	V	Sweden is a member via SNIC. Preliminary grant for 2015, continued funding depends on a long-term operational plan and budget.
SNIC/PRACE, large-scale computation, storage and national user support	Nat/Int (ESFRI)	http://www.snic.vr.se/ http://www.prace-ri.eu/	V	Operational grant until 2016.
SUNET, network and services for digital communication.	Nat	http://www.sunet.se/	V	Evaluation in 2013. Enquiry regarding the future organisation format and strategy in 2014.
WLCG, computer grid for experiments at LHC.	Int	http://wlcg.web.cern.ch/	V	Sweden is a member via SNIC.

APPENDIX 2. ACRONYMS AND DEFINITIONS

ACTRIS	Aerosols, Clouds and Trace gases Research Infrastructure Network
ADS	Accelerator Driven System
ALMA	Atacama Large Millimeter Array
ANAEE	Analysis and Experimentation on Ecosystem
APEX	the Atacama Pathfinder EXperiment telescope
ASTRID	Aarhus Storage Ring in Denmark
BBMRI	Biobanking and Molecular Resource Infrastructure
BESSY	Berlin Electron Storage ring Society for Synchrotron Radiation
BILS	Bioinformatic Infrastructure for Life Sciences
CBCS	Chemical Biology Consortium Sweden
CCS	Carbon Capture and Storage
CERN	European Organization for Nuclear Research
CESSDA	Consortium of European Social Science Data Archives
CLARIN	Common Language Resources and Technology Infrastructure
CTA	Cherenkov Telescope Array
DASISH	Data Service Infrastructure for the Social Sciences and Humanities
DESIREE	Double Electrostatic Ion Ring Experiment
DESY	Deutsches Elektronen-Synchrotron
EBI	European Bioinformatics Institute
ECDS	Environment Climate Data Sweden
ECORD	European Consortium for Ocean Drilling
E-ELT	European Extremely Large Telescope
EGI	European Grid Infrastructure
EISCAT	European Incoherent Scatter Facility
EIT	European Institute of Innovation and Technology
ELIXIR	European infrastructure for bioinformatics
EMBL	the European Molecular Biology Laboratory
EMBRC	European Marine Biological Resources Center
EMSO	European Multidisciplinary Seafloor Observatory
EPOS	European Plate Observing System

ERIC	European Research Infrastructure Consortium
ESFRI	European Strategy Forum on Research Infrastructure
ESO	European Southern Observatory
ESRF	European Synchrotron Radiation Facility
ESS	European Spallation Source
ESS	European Social Survey
EUI	European University Institute
FAIR	Facility for Antiproton and Ion Research
FEL	Free-electron laser
FLASH	light source for free-electron laser
GBIF	Global Biodiversity information facility
GenIV	fourth-generation nuclear technology
GSI	the Geosynthetic Institute
HPC	High-performance computing
ICDP	International Continental Drilling Program
IceCube	South Pole Neutrino Observatory
ICOS	Integrated Carbon Observatory System
ILL	Institute Laue Langevin
INCF	International Neuroinformatics Coordinating Facility
Infrafrontier	Infrastructure for Phenomefrontier and Archivefrontier
in-operando	during the course of
in-situ	inside tissue/material
Instruct	Infrastructure for structure biology
IODP	International Ocean Discovery Program
ISF	Institute for Solar Physics
ISIS	Science and Technology Facilities Council
ISSP	International Social Survey Program
ITER	Experimental reactor for fusion research
JET	the Joint European Torus (European fusion research facility)
JHR	Jules Horowitz Reactor
KAW	Knut and Alice Wallenberg Foundation
LHC	Large Hadron Collider
LifeWatch	an e-infrastructure for biodiversity data
LLB	Laboratoire Léon Brillouin
LNU	The Swedish level of living surveys
MAX (IV)	Microtron Accelerator for X-rays
MIMS	the Laboratory for Molecular Infection Medicine
Myfab	network for microfabrication laboratories
MYRRHA	Multi-purpose hybrid reactor for high tech applications

NeIC	Nordic collaboration for common e-infrastructure
NGI	National Genomics Infrastructure (formerly SNISS)
Nordsim	Nordic Secondary Ion Mass Spectrometer
NOT	Nordic Optical Telescope
NRM	Swedish Museum of Natural History
PETRA	Synchrotron light facility in Germany
PRACE	Partnership for Advanced Computing in Europe
RINFI	Research Infrastructure National Forest Inventory
RÅC	Röntgen-Ångström Cluster
SANS	small angle neutron scattering
SCAPIS	Swedish cardiopulmonary bioimage study
SciLifeLab	Science for Life Laboratory
SEM	Scanning electron microscope
SGU	The Geological Survey of Sweden
SHARE	Survey of Health Ageing and Retirement in Europe
SILS	Systems Biology Infrastructure for the Life Sciences
SIOS	Svalbard Integrated Observing System
SIPRI	Stockholm International Peace Research Institute
SITES	Swedish Infrastructure for Ecosystem Science
SKA	Square Kilometre Array
SLOSH	the Swedish Longitudinal Occupational Survey of Health
SLW	Swedish LifeWatch
SMS	Swedish Material Science beamline
SND	Swedish National Data Services
SNIC	Swedish National Infrastructure for Computing
SNS	Spallation Neutron Source (USA)
SNSN	Swedish National Seismic Network
SSDP	Swedish Scientific Drilling Programme
SUNET	Swedish University Computer Network
Swedstruct	Swedish national infrastructure for structural biology
TEM	Transmission Electron Microscopy
UCDP	Uppsala Conflict Database Program
ETF	Evaluation Through Follow-up
WABI	Wallenberg Advanced Bioinformatics Infrastructure
VEGA	Centre with analysis instruments for earth sciences
VLT	Very Large Telescope
WRAM	Wireless Remote Animal Monitoring, database
XFEL	X-ray Free Electron Laser Facility

APPENDIX 3. MEMBERS OF THE COUNCIL FOR RESEARCH INFRASTRUCTURES AND ITS EVALUATION PANELS FOR 2014

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Thomas Jonsson, KTH

External advisor in the work on the guide: Melvyn Davies, Lund University

Evaluation panel 2: Infrastructure for Molecular, Cell and Material research

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Helene Lundkvist, Swedish University of Agricultural Sciences
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Mats Holmström, Swedish Institute of Space Physics
Fredrik Ronquist, Swedish Museum of Natural History
Roar Skålin, Research Council of Norway
Milena Ivanova, Netherlands e-Science center
Ellen Sherwood, Karolinska Institutet/Science for Life Laboratory

Evaluation panel 5: Infrastructure for Man, Culture and Society

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Bente Maegaard, University of Copenhagen
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Juni Palmgren, Secretary General, Council for Research Infrastructures
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Catarina Sahlberg, research officer in evaluation panel 1
Johan Holmberg, research officer in evaluation panel 2
Elin Swedenborg, research officer in evaluation panel 2
Mats Andersson, research officer in evaluation panel 3
Anna Wetterbom, research officer in evaluation panel 4
Susanna Bylin, research officer in evaluation panel 5
Per Karlsson, research officer, Head of Unit

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The Swedish Research Council's Guide to Research Infrastructures is a plan for how Swedish scientists in academia, government and industry are to have access to the most qualified research infrastructure in Sweden and in other countries. It is the Swedish Research Council's guide for Sweden's long-term needs of national and international research infrastructures. It forms the basis for discussions on the financing of future infrastructure within the Swedish Research Council, but also in collaboration with other research funding agencies nationally and internationally.

Research infrastructure refers to central or distributed research facilities, databases or large-scale computation, analysis and modeling resources. The first edition of the Swedish Research Council's Guide to Research Infrastructures was published in 2006 and updated versions were released in 2008 and 2011. In 2014, the Swedish Research Council conducted a review of the processes of prioritization and funding of national research infrastructure. As a consequence, this edition is limited with regard to proposals for new infrastructure. Instead, its main emphasis is on concentration and coordination of existing infrastructures and the clarification of roles and principles for future management of infrastructures.

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The Swedish Research Council has a leading role in developing Swedish research of the highest scientific quality, thereby contributing to the development of society. Besides research funding, the agency advises the government on research-related issues and participates actively in the discussions to create understanding of the long-term benefits of research.

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