BrightnESS²

Bringing Together a Neutron Ecosystem for Sustainable Science with ESS

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Deliverable report

D4.6 Innovation Capacity Building of ESS

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3. List of abbreviations

ARIES	Accelerator Research and Innovation for European Science and Society
ATTRACT	Breakthrough Innovation Programme for a pan-European Detection and Imaging Ecosystem
BSO	Big Science Organisation
CERN	European Organisation for Nuclear Research
COVID	Corona Virus Disease 2019
DESY	The German Electron Synchrotron
DTU	Technical University of Denmark
ERA	European Research Area
ERIC	European Research Infrastructure Consortium
ESFRI	European Strategy Forum on Research Infrastructures
ESRF	The European Synchrotron Radiation Facility
ESS	European Spallation Source
EU	European Union
GIANT	Grenoble Innovation for Advanced New Technologies
H2020	Horizon 2020
I.FAST	Innovation Fostering in Accelerator Science and Technology
IKC	In-Kind Contribution
IKP	In-Kind Partner
ILL	Institut Laue-Langevin
ILO	Industrial Liaison Office / Officer
ISIS	ISIS Neutron and Muon Source
KPI	Key Performance Indicator
LENS	The League of advanced European Neutron Sources
LINX	Linking Industry to Neutrons and X-rays
LINXS	Lund Institute of advanced Neutron and X-ray Science
MIT	MIT Innovation Initiative
MTCA	Micro Telecommunications Computing Architecture
OECD	Organisation for Economic Co-operation and Development
R&D	Research and Development
RI	Research Infrastructure

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RTO	Research Technology Organisations
SEI	Socio-Economic Impact
SWOT	Strength, Weakness, Opportunity and Threats Analysis
VC	Venture Capital
WP	Work Package

4. List of Relevant BrightnESS² Deliverables in WP4 as reference points

1. Deliverable 4.1 Report on the Evolvement Potential of ESS ILO network
2. Deliverable 4.2 Strategic Roadmap for Technological Upgrades of ESS
3. Deliverable 4.3 Cross-border activities
4. Deliverable 4.4 Processes and Procedures for Targeted Access Routes
5. Deliverable 4.5 Service Catalogue including price list with three use cases

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7. Executive Summary

The European Spallation Source – ERIC (ESS) is a multi-disciplinary research facility that, once fully operational, will deploy the world's most powerful neutron source. It is one of the largest science and technology infrastructure projects being built in Europe today. As a greenfield project, built from the ground up, ESS is offering substantial innovation opportunities that are unique.

The framework of this last deliverable of WP04 is based on all the deliverables throughout the project duration.

- The Report on the Evolvement Potential of ESS ILO network demonstrated how the ESS ILO network can play an important role in the exploitation of the innovation potential and capacity at ESS.
- As ESS has not been able to keep to the schedule envisaged when BrightnESS² commenced, so the Strategic Roadmap for Technological Upgrades of ESS instead evaluated the technology potential and did this from an innovation perspective. The report became a very useful innovation catalogue of technology areas and opportunities against which the innovation capacity building can lean.
- As is to be expected during the construction of a multi-partner facility, there are many cross-border activities. By evaluating a substantial and diverse set of these, ESS's capacity to collaborate on innovation was validated, revealing the significant value of cross-border innovation activities to ESS member countries.
- Finally, WP04 looked at Processes and Procedures for Targeted Access Routes together with the establishment of a draft Service Catalogue, price list and three use cases. These last two deliverables were based on extensive internal discussion and with input from other facilities, building on their best practices. The result has become a reference document for how ESS could engage with the different user groups, how they could access ESS and what scalable service levels could underpin ESS's value proposition and offer.

For ESS to unlock its innovation potential in this context, it naturally needs strong leadership to provide capacity to engage with all the above and it needs a platform from which to promote and collaborate. This report looks at both aspects by asking:

1. How can ESS best build its innovation capacity?
2. What could an innovation collaboration platform look like?

The report highlights the relationship between building internal innovation capacity and the establishment of an ESS Innovation Ecosystem, external to ESS and located in the Nordic Region. The Ecosystem is envisaged as a platform where ESS related stakeholders meet and collaborate within their expertise and area of interest, under an umbrella that also acts as an access point to other relevant ecosystems and hubs worldwide to ensure that ESS's innovation value is experienced by all its Members regardless of location.

Having established the definitions and concepts, this report provides basic recommendations to ESS on how to build innovation capacity via enabling collaboration internally and with the different stakeholders of the ecosystem.

Internally at ESS, the established Innovation Board could offer much, starting with innovation training so participants could appreciate the overall picture and fundamental mechanisms at ESS. Over time, as the innovation organisation matures, the Innovation Board could progressively introduce external and diverse innovation expertise to broaden awareness. The ESS Innovation Strategy should be widely communicated throughout the organisation, supported by clear KPIs and organisational incentives to encourage and reward innovation activities. ESS and/or In-Kind Partner scientists could be offered a short training program in a hosting industry partner or innovation supplier attached to ESS. In the short-term the Innovation Board and the Industrial Advisory board established under the BrightnESS² WP04 could design and test an innovation roadmap for various types of innovation paths that involve external stakeholder collaboration.

To encourage entrepreneurship, ESS may consider providing support by allocating some proof-of-concept funding and helping connect internal entrepreneurs to relevant industry partners, perhaps as a key function of the internal innovation board. ESS is recommended to consider connecting a wide range of entrepreneurs through the network of its internal innovation board, the industrial advisory board, and ILOs and to establish regular networking events to connect them with other ESS stakeholders.

In relation to the funding organisations in Europe, ESS could, as a prominent large RI in Europe, play an influential role showcasing different mechanisms of collaborative innovation with academia and industrial users, providing evidenced cases to clearly demonstrate potential impact to EU funding instruments and national funding organisations. By developing the ecosystem so it eventually contributes to objectives and budgets for projects that create long-term impact, fundamental research could be used to leverage complementary assets of collaborative partners among academia, industry, and public sector organisations in the quest for innovation.

For Academia, it would be beneficial to set up a common interface for communicating and collaboration with ESS, supporting and rewarding dual affiliation, and reward scientific work and joint proposals of grants resulted from the dual affiliation. It would be an advantage to have a fair and transparent technology licensing agreement with the inventors and provide strong support to help the inventors within technology transfer, commercialisation, patenting and even starting up. In the cases of scientists having dual affiliation to a university and to ESS, it is recommended that ESS both comply to European and national IP regulation and provide strong benefits/incentive to the inventors by offering a corresponding set of patenting and technology commercialisation support. A closer relationship with the innovation foundations and academic entrepreneurship projects in the respective member countries could show case successful business cases of ESS' collaborative innovations.

For the industrial partners, ESS's continued engagement with suppliers should begin as early as possible in the tendering process, holding pre-tendering information events for industry where possible, or even inviting suppliers to visit ESS as has been done in the past. To assist this process, ESS should keep its supplier database up-to-date - with the help of the ILO network - and by using market intelligence proactively scout relevant industries for new suppliers to support the pre-procurement ESS-supplier relationship. For the contact to Industry, dedicated personnel with knowledge in procurement and engineering technologies, well-trained in innovation strategy and process, would again expand innovation opportunities. ESS, in time, could also assign dedicated functional personnel to proactively explore the future industry users and collaborative partners among key universities. This function would undoubtedly need targeted resources with both academic experience and extensive industry experience in sectors relevant to neutron science.

For the collaboration with intermediaries, ESS may consider having a dedicated function of innovation office, which ILOs could directly engage with, thus strengthening the relationship with ILOs and national intermediaries. Such strong innovation leadership in ESS, would deliver continuous dialogue among ILOs on ILO networking events, involving ESS leadership, industry representatives from Member countries, and key influencers/policy makers within Science, Technology, and Innovation. ESS' procurement procedures and protocols should continue to follow the best practices of innovation procurement. For example, encouraging early involvement of multiple suppliers in the design and development of challenging innovation solutions for ESS, following EU Commission's concept of Pre-commercial Procurement (PCP).

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All these recommendations are further discussed and described later in the document. It is clear, that to reap the rewards that innovation might bring, ESS will need to move scientific discoveries and technology forward and take a role in the entire process of "taking ideas from inception to impact". To achieve this, the main conclusion in this report is that as ESS moves to full operations, it should develop and maximise a dynamic innovation capacity and apply it to all aspects of its operations. At the beginning of BrigtnESS² it was planned that ESS would move to full operations in 2026, however recent events - including the Covid-19 pandemic - have meant that ESS is not on track to start full operations in this timeframe. A recent Re-Baseline Review has confirmed this is now likely to start in 2028 and, as this information is new, ESS has yet to consider whether to adjust the pace in which it develops its innovation capacity.

8. Introduction

The European Spallation Source (ESS) is a unique project when it comes to neutron science and state of the art technology. Most elements of ESS are challenging both construction, technology, and implementation.

The thirteen-member states that own the facility expect not only excellent science but also impact in many other ways, to deliver full return on their investment. This is particularly the case for the two co-hosting countries of Sweden and Denmark where the scale of investment in the project is significant.

Innovation is one of the expected currencies of payback to the member states, to society and to the World, and, as such, is written into the ESS statutes. However, the transformation of high-tech inventions and scientific findings is not trivial. There is a very limited marketplace for this kind of trade and the bridge between science, technology and industry is not straightforward to build and sustain.

The initial technology and concept selection activities on the BrightnESS project, funded by the European Union Framework Programme for Research and Innovation Horizon 2020, under grant agreement 676548, created knowledge and capacity to support selection of the technical design of ESS. The BrightnESS² project has been the natural follow-on project, safeguarding the long-term sustainability of the neutron community and ESS, together with consideration and implementation of the recommendations from the first project. A very big and important part of these valuable recommendations, is to create, promote and fertilise innovation capacity.

Work Package 4 of BrightnESS² has focussed on innovation from different perspectives, by looking at channels for technology and knowledge transfer, and the many stakeholders that help and support the making of ESS. The essence for all the activities of Work Package 4 is building Innovation Capacity Building in the widest possible sense, including skills, competence, network, culture, encouragement, in short, implementing an innovative mindset for all involved internal and external stakeholders.

The starting position of BrightnESS² was that ESS would benefit from a clear Innovation Strategy that is embedded in the organisation and its future evolution. For this to be possible, an innovation capacity and culture needs to be built and prioritised by the executive leadership at ESS. For such a strategy to be sustainable, there needs to be a healthy, dynamic and encouraging innovation environment or ecosystem.

Inspired by innovative ecosystems from around the world, this document aims at describing the different elements of innovation capacity building and outlining an innovation ecosystem, in which innovation capacity building is best contextualised and enabled. The definition of innovation ecosystem refers to the framework and concept for Corporate Innovation and strategies for leveraging innovative ecosystems by MIT scholars (Budden & Murray, MIT), where innovation is defined as "the process of taking ideas from inception to impact".

With this definition it becomes very apparent that what drives innovation is capacity to control, ignite, plan and fuel this process and to ensure, as much as possible, the birth and implementation of impacting ideas to the world.

This document will first focus on the ESS Innovation Strategy, the building of Innovation Capacity, the concept of an Innovation Ecosystem, and provide recommendations and conclusions for innovation capacity building at ESS.

9. ESS Innovation Strategy

At the very core of ESS, the Innovation Strategy shall support the founding Statutes:

"The basic objectives for the ESS facility are to provide world leading neutron scattering research opportunities for European science, striving for scientific excellence and highest performance in terms of scientific output. The facility is in all its parts designed to meet these objectives and to satisfy European demand for unique, cutting-edge capability and enhanced research capacity. In meeting these objectives, the **ESS will provide new knowledge unattainable with other facilities or methods, will strengthen the societal impact of science, and underpin innovation in Europe.**" For ESS to achieve these objectives, the relevant tasks and activities described in Article 2 are:

1. **"Contribute to top-level research, technological development, innovation and societal challenges thus representing an added value for the development of the European Research Area (ERA) and beyond"**
2. **"The Organisation shall construct and operate ESS on a non-economic basis. In order to further promote innovation as well as transfer of knowledge and technology, limited economic activities may be carried out as long as they do not jeopardise the main activities."**

These high-level objectives are further divided in to strategic objectives concerning innovation:

"ESS develops innovative ways of working, new technologies, and upgrades to capabilities needed to remain at the cutting edge."

As ESS moves towards full operations, a further strategic objective becomes increasingly important: **"ESS supports and develops its user community, fosters a scientific culture of excellence and acts as an international scientific hub."**

The ESS Innovation Strategy has evolved during both the BrightnESS and BrightnESS² projects, continuously following the organisational evolution of ESS. With the construction phase planned to ramp down and the initial operations phase planned to ramp up during BrightnESS², it was anticipated that the innovation strategy would quickly evolve as the facility moved towards full operations. However, recent events have meant that ESS is not on tract to start full operations in 2026 and a recent Re-Baseline Review has confirmed this is now likely to start in 2028. As this information is new, ESS has yet to consider at what pace to develop its innovation capacity and ensure this is supported by policies and plans for the future perspective on a short-, medium- and long-term horizon:

BrightnESS

- Work Package 3: Organisational Innovation
- Work Package 4: Innovation of Key Neutronic Technologies: Detectors and Moderators

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- Work Package 4: Innovation and industry
    - Propagate and implement recommendations for an ESS Innovation Strategy, including the establishment of a framework for the engagement of industrial users at ESS, and adopt ESS Innovation Strategy in line with the recommendations;

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- Establish an innovation culture at ESS through collaborative schemes and capacity building trainings;
- Evaluate the potential of the Industrial Liaison Officers (ILO) Network nodes, increase their portfolio and competence, and help them to become active contributors to the ESS innovation framework

Based on the activities during the BrightnESS projects, it was planned that the ESS innovation strategy would be implemented by several functions and mechanisms: (1) market pull by procurement and In-Kind Contribution, (2) technology push by knowledge transfer and commercialisation, and (3) by fostering and supporting Innovation capacity of academic and industrial users in Member Countries. To achieve these, it was anticipated that ESS must exploit its own innovation capacity.

Market Pull by ESS

Building a neutron facility of this magnitude and involvement of specialised technologies requires world-class expertise, cutting-edge technologies, and innovation. That is why ESS works closely with suppliers and In-Kind Partners in the Member Countries to make technological and process innovations and build innovative capabilities within ESS and with partners. This is achieved through joint R&D, via In-Kind Contributions and through specialised procurement that add innovation value to the suppliers in Member Countries. In doing so, knowledge transfer and positive spill-over effects in a medium to long run will contribute to innovation capacity building at ESS and among the Member Countries.

The ESS IKC model is innovative and creates the opportunity to enrich knowledge, skills and business in each Member Country – thus benefitting ESS membership already in the Construction Phase. The benefits are expected to exceed the direct relationship between ESS and its In-Kind Partners, through collaborative projects beyond the scope of the In-Kind Contributions, encouraging future users, and procured R&D. As an example, the in-kind model has enabled the creation of ESS Bilbao in Spain, where the ESS contributions have built on the existing engineering skills of the region and demonstrated that the investment by the Spanish and Basque governments has made positive impact on the local, national, and international level. Similarly, by working with ESS, suppliers may benefit in terms of developing new technologies, products, and services, and potentially extending market opportunities. Thus, in pursuit of this strategic objective, ESS makes its impact by uplifting technological innovation capacity of itself and of In-Kind Partners and industry in the Member Countries. During full operations, technology and instrument upgrades are expected, which continues to offer opportunities for suppliers and IKPs to innovate.

Technology push by ESS

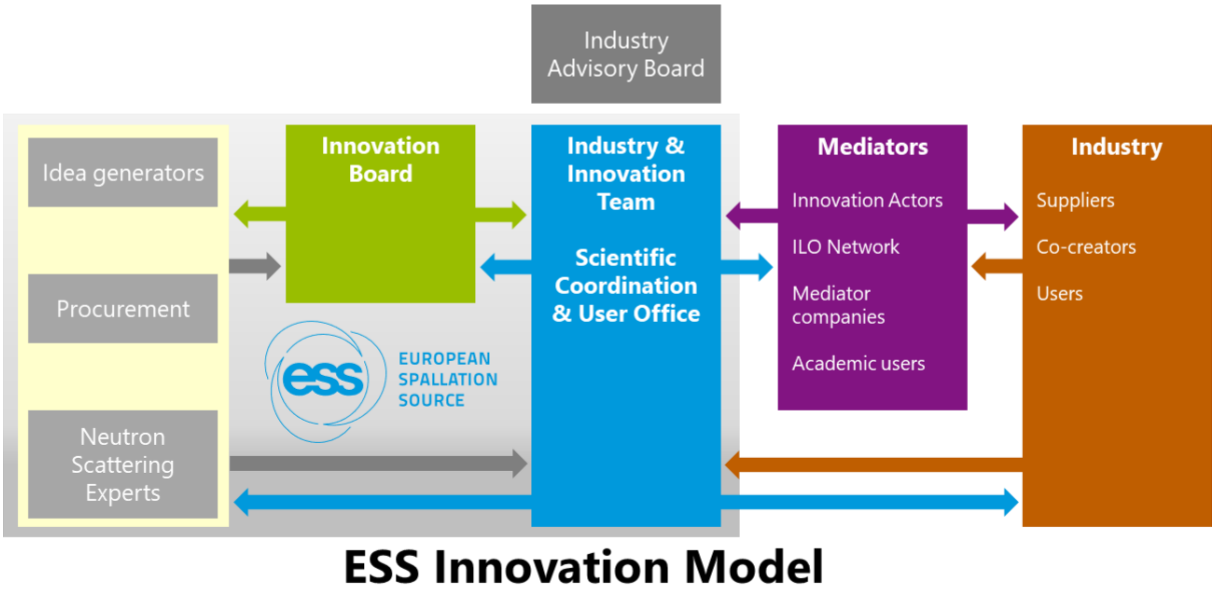
During the construction phase, several cases have shown that ESS' internal R&D has generated scientific and technological breakthroughs, which have potential to be applied by other Research Infrastructures (RIs) or by other industries. Examples can be found scattered all around ESS: standardisation and improvement of the standard MTCA technology for control systems, Klystron Modulators for DC grid development and the Boron-10 detectors, just to mention a few. ESS's own innovation capacity in this respect must be strengthened and maintained not only by sustaining the technological advance, but also by creating and developing an organisation with the right culture, structure, and incentives for ESS' scientific staff to be motivated to engage in innovation through, for example, technology transfer, IP application, spinouts, and other forms of technology commercialisation.

Support and co-create with users

During full operations, ESS will welcome an increasing number of academic and industrial users, which are the key sources of scientific advance and potential further technological inventions. This will require comprehensive knowledge about the needs of academic and industrial users, their collaborative relationships, barriers for industrial use of neutron sources, as well as careful planning and implementation.

As a baseline for the innovation strategy, the following model in Figure 1 is established at ESS:

Figure 1 The ESS innovation model



As can be seen, the industry and innovation function are in close collaboration with the scientific coordination and user office. It is important that the two functions work back-to-back and create a joint capacity, with a seamless transition capability between them.

The main focus areas and targeted actions of the ESS Innovation Strategy are:

1. Innovation harvesting of existing innovations
   Other innovations in the organisation will be captured and described to create awareness and promote recognition. Communicating these examples internally and externally will highlight innovation by focusing on both the innovation value and the individual(s)
2. Promote Open Innovation at ESS
   Establishing collaboration and relationships with world leading science within selected areas will attract industry and create societal value. In return, this will support the evolution of the innovation strategy at ESS.
3. Establishing a commercial ESS technological transfer platform
   ESS can benefit from enabling and promoting innovation and entrepreneurship. Many of the ESS innovation activities are cutting-edge solutions that can potentially create value in companies, public institutions, and society in general

10. Innovation Capacity Building

10.1. State-of-the-art

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Capacity building is a construct with many definitions and units of analysis in academic studies and there is not any generally agreed definition for it (Labin et al., 2012; Jensen and Krogstrup, 2017; Brix, 2018). Capacity building is both a process and an outcome: it is a process because the focus is on improving the existing capacities of individuals; and it is also an outcome because the system is improved as result of this capacity building process (Jensen and Krogstrup, 2017). In general, the literature frames capacity building as an improvement process that focuses on the actions and interactions of an organisation and its employees to seek their full potential and it is also commonly accepted that innovation capacity building includes two levels: organisational level and individual level (Brix, 2018; Prajogo and Ahmed, 2006). Both levels are important because the existing capacities of the organisation and its employees define the strategies that need to be realised, improved, and refined (Farazmand, 2004; Labin et al., 2012).

Based on the typology of Prajogo and Ahmed (2006), organisational capacity building includes the following elements:

Leadership

Far-sighted leaders make the difference by strategically exploring short-term and long-term opportunities created through new technologies, key competencies and market applications. Leadership is key in shaping a 'fertile' environment (i.e., organisational culture) to nurture innovation.

People management

Creating an innovation culture by empowerment, including provision of knowledge or feedback. Empowerment should make people feel they possess a certain degree of autonomy, feel less constrained by organisational, technical or rule-bound aspects and self-efficaciousness in enacting their work; in combination these features enable and motivate people to be innovative. For scientific research organisations, this means encouraging scientific staff to explore technology development and market application, beyond the primary goal of scientific discovery.

Knowledge and Creativity management

Innovative organisations must have effective knowledge sharing system, fostering a context for innovation by establishing creativity stimulation and step out of the comfort zone. For scientific research organisations, this means maturity and ability to transform scientific knowledge via technology or operational development, all the way to an e.g., commercial, social, cultural, environmental impact. This transformation should not be seen as taboo, but instead, knowledge sharing, and creativity stimulation should be a common denominator across the domains of science, technology, and impact.

The literature has also paid attention to the life cycle of organisations, for which innovation capacity building must be considered differently at different stages of the life cycle. For instance, early start-ups and small companies usually have a focused strategy and remain innovative, as the culture and incentives are built upon energies of creating new solutions, while large and established industrial firms are facing the dilemma between remaining operational excellence (i.e., efficiency and effectiveness in their core business) and exploring new growth opportunities in the future that deviates from the company's existing technology base and markets (March 1991). Public organisations, such as municipalities, public universities and hospitals, and research institutes, normally do not have a primary objective to commercialise technologies. Therefore, the focus on developing innovation capacity may not be on the top of their operational agenda at the early phase of the organisation's life

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cycle, even though the wording of "innovation" may appear explicit and strong in the organisation's strategic corporate communication (De Vries et al., 2016).

10.2. Interpretation of "capacity building" for the future of ESS

European Research Infrastructures (RIs) play a crucial role to deliver scientific breakthrough and to foster innovation through the technological break-troughs and scientific excellence. Given the broad consensus on the need to address the societal challenges facing Europe and the world, science has an important mission to create and sustain societal impact, of which innovation is a crucial element. As mentioned before, innovation capacity building is not only a key component in the WP4 for BrightnESS², but a strategic focus of ESS in its overall strategy and policy throughout its lifetime.

The life cycle of the facility is divided into several phases. The Construction Phase started in 2013, when the ground-breaking ceremony took place in September 2014. It is currently running in parallel to the Initial Operations Phase (2019-2025), although it is now clear that this phase will be extended by two years. First Science is planned to begin toward the end of this period, and the Steady State Operations Phase to now begin in 2028. For RIs, the predominant innovation mechanism during the construction phase is through own technological development and procurement by which industrial suppliers and research partners are "pulled" to develop new technological solutions to address the challenging demand from the RI (Autio, 2014). However, during the operations phase, innovation will evolve through various mechanisms, e.g., through procurement during upgrading, industrial users, internal staff's invention, collaboration with universities partners, knowledge transfer and spillover, etc. Thus, as ESS approaches the end of the Construction Phase and transitions into the Operations Phase, the focus on innovation evolution and capacity building must be brought up to the top of the ESS agenda.

To contextualise the meaning of "Innovation capacity building" for ESS, we must revisit the original rationale of the ESS strategy, reflected in the BrightnESS² Project proposal. First, in the BrigtnESS2 Project Annex 1 Task 4.1 clearly depicts that "*Capacity building training activities will be organised for ESS staff to increase their understanding of industrial needs, improve their skills to engage with industry, and further develop human capital. The Scientific Coordination and User Office shall be an integral part of the innovation team. Principles of internal incentive system in support of innovation activities will be defined. The principles will address questions related to innovation time, recognition of innovation achievements at ESS, the role of innovation in career paths, incentives for scientists to contribute to industrial R&D in a balanced way especially when compared to method development, user service, and curiosity-driven research etc."* Meanwhile, Task 4.3 also mentions that to prepare for industrial users, ESS must *"Fostering innovation by capacity building: Exchange of staff between neutron sources, mediators and industry will be supported to facilitate knowledge sharing and develop human capital."*

In addition, ESS also defined the most important elements of its innovation strategy, including

- Provide guidance for the implementation of the ESS innovation framework, considering relevant policies.
- Ensure a common understanding of innovation across ESS and encourage an innovation culture at ESS.
- Maximise impact of ESS throughout its entire lifecycle, considering the different project phases and priorities.

To implement the innovation strategies, thus, it is clear that ESS must foster and develop innovation capacity of its organisation and employees when transitioning forward towards the Operations Phase, although the Re-Baseline Review has operations at ESS will now start in 2028.

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The complex interactions among ESS internal individuals and units and external suppliers, collaborators, and users makes it necessary to discuss Capacity Building in the context of an innovation ecosystem where all stakeholders are represented.

11. What is an Innovation Ecosystem?

Innovation ecosystem is a concept that just caught researchers', practitioners', and policy makers' attention during the last five years or so. Innovation ecosystem refers to "…the alignment structure of the multilateral set of partners that need to interact for a focal value proposition to materialise" (Adner, 2017: 40), or "…clusters (physical or virtual) of innovation activities around specific themes (e.g., biotechnology, electronics, pharmaceutical and software)" (Ritala et al., 2013: 248). Although having many definitions, an innovation ecosystem is the evolving set of actors, activities, and artefacts, and the institutions and relations, including complementary and substitute relations that are important for the innovative performance of an actor or a population of actors (Granstrand and Hoglersson, 2020). Following this definition, we highlight the important factors for an innovation ecosystem. First, an ecosystem emerges within a boundary of institutions, including policy, rules of law, norms, which governs the interactions of the actors within an ecosystem and across different ecosystems. Institutions also adapt to the evolution of an ecosystem when new types of actors, activities and artefacts emerge. Second, actors are the stakeholders in an ecosystem, each has a distinct role to play, while being interdependent on each other. These actors often include government, industrial firms, risk capital (e.g., venture capital), universities and other public research institutions, and last but not least, individual innovators and entrepreneurs. Third, within an innovation ecosystem, actors perform various types of activities which require so-called innovation (and sometimes entrepreneurship) capacity. Scholars from MIT Lab for Innovation Science and Policy suggest that the intertwined innovation and entrepreneurship capacities are a crucial element of an innovation ecosystem (Budden and Murray, 2019). Capacity and activities are two sides of the same coin: capacity is needed to perform activities, while the performance of activities demonstrate, reinforce, and likely enhance capacities. Finally, artefacts refer to tangible or intangible technologies, products, services, and resources, based on which value can be created by some stakeholders and captured by others so that collaborative interactions will find incentives to take place.

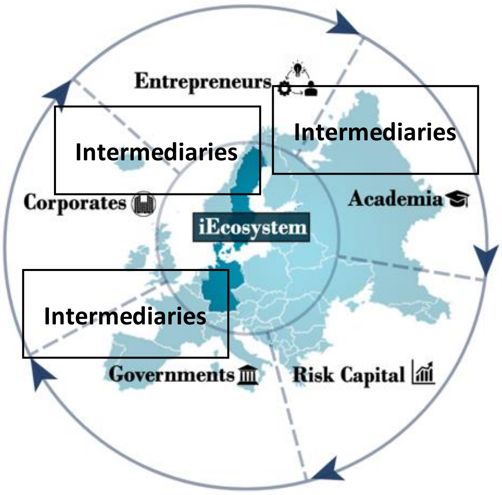
The ESS innovation ecosystem is expected to shape a cluster of innovation activities round material science within the technology fields of neutron by linking relevant industries which supply technologies to, adopt technologies from, and co-develops technologies with the core of research at ESS, partner universities, and other relevant RIs in Europe. It requires a structure, a network, and a process to create value among stakeholders within such an ecosystem. The governing institutions for the ESS innovation ecosystem are a complex net of European Research Infrastructure Consortium (ERIC) under European Commission's Research and Innovation policy, the founding Statutes of the European Spallation Source, ESFRI guidelines, EU public procurement rules, and objectives specified in BrightnESS and BrightnESS² projects, etc. Figure 1 below illustrate a preliminary conceptualisation of how actors within ESS and external to ESS may interact to engage innovation.

A simple overview of various types of stakeholders of ESS's innovation ecosystem is illustrated in Figure 2, which is built on the framework suggested by Budden and Murray (2019).

1. **Entrepreneurs** (individual innovators): creative individuals as innovators and entrepreneurs are the fuel of an innovation ecosystem. Innovators may come from within (as an employee inventor) or outside of ESS or from university partners, industry, or start-up community. They take technological and/or commercial risks to create value for customer needs by offering improved or new solutions. Creative individuals as such will be reluctant to take risks and seise opportunities if there is a lack of innovation culture and supporting organisation structure.

2. **Funding organisation** (including risk capital): ESS' innovation ecosystem needs substantial funding as the backbone. This includes significant funding from Member States plus relevant EU funding (e.g., Horizon Europe, European Institute of Innovation and Technology, European Innovation Council, EU Regional Development Fund), national public funding (e.g., the Danish Innovation Foundation), industry funding (e.g., Novo Nordisk Foundation, Danish Industrial Foundation, and Carlsberg Foundation), and private foundations, and venture capital (VC).

Figure 2 Types of Stakeholders in ESS Innovation Ecosystem



3. **Academia**: University as a stakeholder is regarded as a source of innovation and state of the art technology, Ph.D. and Post Doc programs, scientific excellence, dynamic sample environment, and lab resources. Different universities will have different core competencies and strategies that need to be incorporated. Academia will play a vital role in the innovation ecosystem. Among the ESS local region, for example, Lund University, Copenhagen Capacity, and Technical University of Denmark are natural points of contact for ESS to maximise outreach activities targeting entrepreneurs in the immediate vicinity of the facility. The rich tradition in innovation and entrepreneurship, as well as a collaborative spirit, makes the universities ideal for research and development in the science field. The university as a stakeholder can continuously bring new perspectives from different and unexpected angles and make them crucial partners in the search for trend-setting and sustainable innovation.

4. **Corporate/Industry**: The industry can also stimulate innovation by establishing research centres in the vicinity of research facilities and by developing a strong licensing relationship with research facilities. As an international partnership, ESS collaborates with industry and companies from a few countries in Europe and beyond. The industry will become a key actor within the ecosystem, supply innovative technology and instruments, and continuously search for innovation capabilities.

5. **Government** is one of the key stakeholders and plays an important role in strengthening the innovation ecosystem. The various government actors integrate resources to build and mature an innovation ecosystem powered by funding, national technological policies and enhances the close collaboration between industry and university through investments and sustainable funding, in academia, R&D, corporate technology innovation, entrepreneurship, and corporate export capability enhancement.

6. **Intermediary organisations**, including specialised innovation hubs/platforms and Industrial Liaison Officer (ILO) network: Innovation intermediaries facilitate inter-organisational collaboration bringing together firms, governments, and universities to address innovation-related challenges and promoting entrepreneurship, bringing about economic development (Dalziel, 2010). Intermediary organisations' value to their network participants extends beyond knowledge brokering activities into broader systemic innovation management (Howells, 2006; Kilelu et al., 2011). The increasingly uncertain situations that intermediaries face when supporting the innovation process of their network participants give rise to high complexity in their roles and activities (Agogué et al., 2017). ESS has a large and effective ILO network that translates ESS's demand for technology and instruments into industry's interests and capacity of supply, a crucial role to enhance ESS and its ecosystem's innovation capacity. In addition, in some member countries, specialised innovation platforms have also been

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established to foster science and industry collaboration in neutron and x-ray, e.g., the LINX Association in Denmark and the LINXS in Sweden, which complement the role to those of the ILOs. It is worthwhile to explain in detail regarding the different roles played by different stakeholders in the ESS innovation ecosystem.

It is worth noting that some stakeholders play different roles in relation to ESS in the ecosystem. For example:

1. Users: The long-term sustainability of the European Spallation Source (ESS) is dependent above all on sustaining and further developing the community of European neutron scientists and facilities, as well as industrial firms – the future users of ESS. For its scientific success, ESS must be directed by the scientific and innovation needs of its future users. The need for ESS long-pulse neutron source and corresponding instrument suite is the result of a bottom-up neutron user driven approach. Even though it is still in the Construction Phase, ESS has been actively building its future user community and broadening its network through collaborative research supported by various activities. Typically for ESS, the users include academic users (e.g., university researchers. As much as 85% of beam time available in Europe is used by academia) and industry users (large established companies or small-medium-size enterprises). BrightnESS² Deliverables D4.4 and D4.5 have made detailed description about how ESS is prepared to provide industry users with supported and manageable processes and procedures to access ESS' instruments.
2. Suppliers: Suppliers are a crucial stakeholder for RIs' innovation (Florio et al., 2016). Even though ESS is transitioning towards the Operations Phase, there will be plenty of opportunities for technological upgrading, for which ESS can actively collaborate with industry suppliers and In-Kind Partners (IKPs) to innovate (see BrightnESS² Deliverable 4.2 Strategic Roadmap for Technological Upgrades of ESS). Li-Ying and co-authors (2021) outlined five different modes, in which RIs may innovation in collaboration with suppliers.
3. Co-creators, including universities, other RIs and RTOs as collaborators. Universities are typical scientific collaborators for BSOs. This type of collaboration can be achieved by various means, e.g., dual affiliation of scientific staff, joint research grant, exchange of researchers and PhD students, and other formal and informal knowledge exchange. Other European and international RIs that are in the scientific scope of neutron and synchrotron are also often collaborators rather than competitors. ESS has performed a comprehensive scanning of the European neutron source facilities in relations to future potential users in a report of BrightnESS (NEUTRON USERS IN EUROPE: Facility-Based Insights and Scientific Trends, 2018), in which an overview of other relevant RIs in Europe have been asked to define their capacity of beam time. Finally, another type of co-creator is Research & Technology Organisations (RTOs), which as their predominant activity provide research and development, technology and innovation services to enterprises, governments, and other clients. Some RTOs has private ownership and are for-profit. However, RTOs differ from private companies and universities because they are supposed to have significant core government funding, supply services to firms individually or collectively in support of scientific and technological innovation and devote much of their capacity to remaining integrated with the science base. RTOs have played a crucial role to bridge the gaps among RIs, universities and industry (Albors-Garrigos, Zabaleta, and Ganzarain, 2010).

Table 1 below illustrate potential multiple roles a stakeholder may play.

Roles *Stakeholders*	Users	Suppliers	Co-creators	Funding/Capital providers

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Entrepreneurs	*Proof of concept, initial studies, intermediaries*		*Learning from others, partnering, entrepreneur-in-residence, collaboration, cross-fertilisation*	
Funding organisation				*Allocate and provide various types of funding to projects with different levels of assessed risk, set science, tech, and development objectives, encourage partnerships, and nurture opportunities for new ventures*
Academia	*Transformation of scientific knowledge to innovative and impactful applications*	*Scientific evolution of products and services, joint projects, providing scientific and technological know-how*	*Collaboration, dual affiliation, competence exchange, access to talents (e.g., PhDs and Postdocs), feasibility studies, support, inspiration, and provide scientific and technological know-how*	
Corporate/Industry	*Proprietary or joint R&D activities to test new products and services*	*Innovation through procurement, reference and reputation, technology development and potential new market, and knowledge transfer*	*Collaboration, industrial PhD projects, joint projects, and proprietary R&D activity*	*Support to engage with RIs, helping to work with aspects of risk*
Government		*Support for risk coverage, funding, In-Kind focus areas, standards*		*Provide funding or other tangible or intangible assets in line with economic or political purpose; work with regional, national, and international development schemes*
Intermediary organisations	*(Scout and nurture new users; promote the use of RIs and specify needs of users; networking)*		*Moderate communication and relationship between users and RIs; extend user and collaborator networks; discover opportunities for further funding and/or entrepreneurship*	*Search and identify complementary funding sources to benefit users' R&D; help to lobby the needs for public R&D funding for academia and industrial users and RIs*

Table 1 Types of stakeholders vs. various potential roles in relation to ESS

As the roles of different stakeholders are intertwined, innovation capacity building must be discussed from an ecosystem perspective, instead of being limited to a single RI's organisation. To build innovation capacity among stakeholders in a complex ecosystem, the organisation not only needs to attend to detail interventions but also needs a helicopter overview, taking views from each stakeholder in a specific context. In the next section, some examples of other relevant RIs current practices are

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briefly described. After that the current strength and weakness of various stakeholders around ESS are addressed and future opportunities and threats are discussed (SWOT analysis).

12. Current practices of other relevant RIs

During the execution of Work Package 4, there has been an extensive dialogue with the different project partners, as well as other reference RIs in Europe, to explore and understand current practices and priorities.

The ecosystem at CERN is probably the most mature, with bespoke functions and invested resources in technology and knowledge transfer, innovation funding through the ATTRACT program (Horizon 2020 GA No. 101004462) and a dedicated entrepreneurship program. During discussions, CERN expressed great interest in the innovation ecosystem as a portal for collaboration.

At DESY in Germany and PSI in Switzerland, there are concrete activities to promote innovation and capacity building in physical surroundings, Park Innovare at PSI and the Innovation Factory at the premises of DESY.

Also, at ESRF and ILL the innovation campus GIANT is taking shape, where different stakeholders create a promising ecosystem for innovation and capacity building as is the Harwell Campus in the UK built around the Diamond Synchrotron and ISIS spallation source.

The European landscape of RIs suggest a paradigm change from a primary focus on excellent science to impact and value generation through application of science, which calls for innovation and capacity building.

From a European perspective, these different facilities and ecosystems need to find mechanisms and subjects for collaboration in an even bigger European ecosystem, forming a dynamic organism that ignites the European innovation power and capacity building skills to its fullest.

13. Building Innovation Capacity around ESS within the ecosystem of neutron science and relevant industries

Having outlined the concept of innovation capacity building and the view of innovation ecosystem, the following section analyses future strategies and approaches to build innovation capacity for all relevant stakeholders within the ecosystem, not just ESS itself. To start with, a SWOT analysis summarises the key strength, weakness, opportunities, and threats of stakeholders with respect to innovation capacity building. The SWOT analysis provides visible areas where ESS and the stakeholders can take actions in a short-term (the next 1-2 years) and in a long-term (5 years into the Operations Phase). Concrete recommendations are highlighted with bold letters. Please note that the role of government is not included in the discussion for two reasons: first, the European and national science and technology policy is assumed to remain relatively stable during the next 5 years or so; second, to suggest concrete actions for its various Member governments is not appropriate for ESS or any individual stakeholder to make. The following subsections will elaborate on the SWOT for each stakeholder and make recommendations accordingly drowning.

	Strength	*Weakness*	*Opportunities*	*Threats*
ESS	Palette of scientific and technical challenges makes a phenomenal playground for innovation capacity building.	The ESS organisation is not currently tuned in to maximise the value proposition of the innovation capacity,	The capacity can be generated in collaborations with external stakeholders, facilitating innovation and capacity impact.	Focus at ESS needs to be on construction and completion, with ESS schedule delayed by two years. This might require a shift in the

	Already during the Construction phase, positive innovation impact demonstrated from suppliers and In-Kind Partners. Close collaboration with ILO Network and In-Kind Partners. Improved procurement system.	which might weaken ESS long term. Innovation culture and focus have not been fully developed in ESS. Innovation Board and Industry Advisory Board only newly established and lack formalised communication channel, decision making or influencing power. A full picture/vision and fundamental mechanisms of ESS innovation unclear to employees and leadership.	Innovation set as strategic priority in BrightnESS². New Director General resumed office to take leadership. ESS moving thinking about approach for coming Operations Phase, will need to more actively engage industry users.	strategic importance of innovative capacity building. COVID-19 continues to hold industry back from external R&D investment. To year delay in ESS schedule will have knock-on effect on demand for using ESS facilities.
Entrepreneurs	Open-minded to challenges and can think outside the box. The diverse angle and view can enable unexpected and high-value capacity building	Often lacking maturity in considerations and consequence determination. Limitations due to resources, human and financial constraints.	Can be engaged with other stakeholders that are enhancing and complementing the strengths, and by that enabling the innovation impact. The emerging role of surrogate entrepreneurs.	Bureaucracy and administrative tasks not aligned to innovative mindset. Lack of financial resources and commercial stamina. Potential for aggressive partners to take advantage.
Funding organisations	Research R&D still strong in Europe, especially among key Member Countries of ESS (e.g., Sweden, Denmark, France, UK and Germany). Diversity in levels and nature of funding to cover various types of research.	The application process and procedure might be too complex and short-noticed with little chance to succeed. Often focuses on moving forward towards higher levels of TRL, with limited appreciation of the innovative capacity building.	A phased approach where funding and risk consciousness follow the evolution of the project, produce, knowledge and human resource(s). A focus on innovation collaboration and long-term impact.	Risk avoidance, too high expectations to return on investment too early, lack of recognition of innovation capacity as an important asset. Too-narrowly focused on Green Transition rather than focus on neutron science and related technologies.
Academia	Depth of scientific and technological competence and knowhow. Leverage possibility when challenges occur. Excellent ability to move innovation capacity forward and to move boundaries. Many university scientists have dual affiliation to ESS.	In an innovation perspective, the focus and priority of publication can weaken the collaboration. Often scientists do not have the entrepreneurial skills for the next phase The IP rules grant IP of a technology invented by a professor to the university by default and if there is no fair mechanism of tech	There is an enormous potential in engaging academics/scientists in innovation capacity building and there is a great impact and value in getting innovation recognised as a currency for science. Several national-, regional-level platform to support (incl. grants) academic entrepreneurship.	A scientific culture that is not challenged and engaged with innovation will not impact innovation capacity to the extent possible. The lack of excitement and recognition is a demotivation. Potential conflict of IP rules of university vs. IP rules of ESS ERIC when

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	In-Kind partner universities made significant contribution to the science and technology development of ESS.	transfer to the inventor, then academia is lacking incentive to pursue innovation and entrepreneurship.	Innovation has been included as one of the KPIs for academia in some leading universities.	the inventor has dual affiliation.
Corporate & Industry	The innovation capability and capacity have become some of the most important assets of knowledge-based companies. Leading innovation companies have realised and benefited from collaborative innovation with Big Science Organisations, and paid attention to ESS instruments. Industry suppliers found Big Science Business Forum (BSBF) highly relevant and demonstrated innovation and economic benefits from supplying ESS.	Creating and cherishing forefront innovation capacity building requires a high degree of maturity, transparency, and a feedback culture. If any of these parameters are missing, short term shareholder satisfaction will often takeover. Many SMEs are either unaware of or inexperienced with dealing with ESS due to lack of knowledge about business opportunities and procurement procedure.	Innovation capacity can be promoted as an important asset that need an "asset management strategy". By enlightening the direct and indirect value and impact, a better appreciation and priority could be established. Evidence is convincing that supplying ESS creates positive innovation, economic and reputational benefits for industry. Evidence is convincing that collaborative innovation relationship between ESS and corporates generates strong positive innovation and societal impact. ESS ILOs focus on innovation and help industry suppliers to innovate while meeting the needs of ESS. Other intermediaries facilitate collaborative R&D with ESS.	Innovation capacity building requires investment and time. These two elements are often threatened by quarterly profit/loss reporting and quantitative management KPIs. Economic return from supplying to ESS does not substantiate and direct impact on further innovation unclear.
Intermediary organisations	ESS ILO network established strong connection with industry in Member Countries and holds regular meetings and events to prioritise innovation. Other national platforms (e.g., LINX in DK and LINXS in SE) have accumulated invaluable experience	The level of focus on innovation in industry varies among ILOs in different Member Countries (Deliverable 4.1 Report on the Evolvement Potential of ESS ILO network). ILOs lack of personnel and capacity to focus on innovation.	EU promote innovation procurement. Green transition policy calls for sustainable innovative solutions. ESS is considering what is needed as it moves into Operations Phase, with opportunities regarding upgrading (D4.2)	ESS anticipating 2-year delay before Operations Phase, less public tenders to supply over extended period. Possible discontinuity of cross-national and national platforms jeopardises knowledge accumulation and sharing.

	to boost collaborative innovation among public and private stakeholders.	National platforms lack of sustainable funding. Lack of unified innovation strategies and coordinated efforts.		

Table 2 SWOT analysis for ESS stakeholders' innovation capacity building

13.1. For ESS

The strength of ESS in its current state is that ESS has been a palette of scientific and technical challenges, making it a phenomenal environment for innovation capacity building. Already during the Construction phase, positive innovation impact demonstrated from suppliers and In-Kind Partners (see ESS Socio-Economic Impact Report 2021, BrightnESS² Deliverable 5.4). ESS has also established close collaboration with ILO Network and In-Kind Partners since 2013. Recently, ESS also improved its procurement system, making it transparent and easy to use for industry suppliers (see BrightnESS² Deliverable 4.1 Report on the Evolvement Potential of ESS ILO network). During the Construction Phase, many innovation cases have emerged as the results of collaboration among ESS scientists, engineers, industry partner and suppliers, and In-Kind university partners. ESS employees to a great extent have been empowered by extended knowledge on the forefront of neutron science demand, industry's capacity to innovate, and societal impact at large. Various professional training programs have been provided to relevant employees to consolidate the foundation of knowledge and skills most important to the development of ESS. Training was also provided to external parties with objectives to nurture future users. For instance, ESS collaborated with MAX IV to build user capacity by directly financing experiments and providing training and supervision for PhD and postdoc researchers. They provided 1,000 months of training and 500 months of learning, which includes an educational component of courses, workshops, and summer schools (see ESS Socio-Economic Impact Report 2021, BrightnESS² Deliverable 5.4). ESS will continue to have a strong hold on these aspects to build a solid foundation for innovation.

However, there has been *weakness* within ESS with respect to innovation capacity building. As ESS considers how to approach the final stages of the Construction and Initial Operations Phase, it is not currently fully mobilised to maximise the value proposition of the innovation capacity. Some excellent steps in the right direction have been taken, including establishing the ESS Internal Innovation Board and Industry Advisory Board, however both need to establish a formalised strategy that relates to the revised status at ESS arising from the schedule delays encountered in implementing the project by ESS and the In-Kind Partners and due to the COVID-19.

There are some concrete actions that could be prioritised in the short- and long-term. First, in *a short-term*, **the internal innovation board members could take training on innovation subjects to fully grasp the overall picture and fundamental mechanisms of innovation around ESS so that they can play a stronger role in implementing the Innovation Strategy and culture at ESS. Second, the Innovation Board could expand its membership to include about 20% of external board members to bring in fresh perspective and information about best practise.** Next, as ESS plans for the future Operations Phase, **it is important to widely communicate the Innovation Strategy throughout the organisation**. The strategy and culture will only be implemented and show results when employees find encouragement to innovate and this will require strong leadership. **This requires clear KPIs and organisational setting that reward collaborative innovation attempts.** In a *long-term*, ESS is

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recommended to take a keystone player's role in the ecosystem by, for instance, **initiating and driving cross-facility and multi-stakeholder platforms to connect stakeholders and jointly create value.** Establishing a coordinated platform that plays a role in objective setting and future funding will take time and will not be straightforward as these ideas go beyond those that are operating anywhere in Europe today However, several of CERN's initiatives are good examples that ESS could build upon, e.g., IdeaSquare, ATTRACT, ARIES, I.FAST, etc.).

Subject to priority, resources and funding, there are also plenty of opportunities for innovation capacity building. First, Innovation has been set as strategic priority in BrightnESS²and against this background, the building of innovation capacity can be clearly communicated and prioritised through collaborations with external stakeholders, facilitating innovation and capacity impact. Second, as ESS plans for its move into the Operations Phase, it should be prepared to be more actively engaging industry users, based on the newly suggested procedures of user access routes and potential service catalogue (see BrightnESS² Deliverable 4.4 Processes and Procedures for Targeted Access Routes and Deliverable 4.5 Service Catalogue including price list with three use cases respectively). In the medium- to long-term, innovation training for employees and extended programs to external stakeholders could be installed and monitored in ESS' organisational KPIs (see ESS Socio-Economic Impact Report 2021, BrightnESS² Deliverable 5.4). ESS could, for instance, be inspired by CERN's I.FAST project, which basically provides cross-facility industrial engineering-in-residence training. ESS may consider engaging in projects such as **entrepreneur-in-residence and/or scientist-in-residence**, much as it has engaged in artist-in-residence programme to promote outreach activities. The former invites future entrepreneurs to receive training at ESS or an In-Kind Partner university to discover the technological and market opportunities around neutron science and other related technologies, while the latter invites ESS or In-Kind Partner scientists to receive a short training program in a hosting industry partner/innovation supplier. Moreover, **in the short-term the internal innovation board and the industrial advisory board can design and test an innovation roadmap for various types of innovation paths that involve external stakeholder collaboration.**

While strength is consolidated and opportunities seised, there are threats, which must be carefully managed and mitigated. The most important, in the short-term, it is likely that the focus at ESS will be fully on the completion construction to the exclusion of many other activities, which may result in a temporary delay in actions to build innovative capacity even through the strategic importance is not downplayed. While ESS has yet to determine the right balance at this point in time, one way to mitigate the impact of any slowing down is to fully promote the existing innovation success cases within ESS and among stakeholder to raise awareness. **ESS leadership should pay special attention to innovation towards the Operations Phase, as the subject is likely to lose in the balance against the priorities of delivering the project.** Another threat comes from outside of ESS: that is the ongoing COVID-19 pandemic will be holding industry back from sustaining or increasing external R&D investment, resulting in less future interest or demand for using ESS facilities**. Even though ESS now has a 2-year schedule delay and the impact of COVID-19 is out of ESS' control, it is strongly recommended that ESS revisit and gradually adapt the proposed access route procedure and process for industry users to make it more attractive**. This needs not only ESS' effort, but also support from intermediary organisations (see discussions below).

13.2. For Entrepreneurs

Individual entrepreneurs are an important part of any research infrastructure innovation ecosystem because they are the ones to connect the dots to create new opportunities and value while taking risks. Entrepreneurs in the ESS ecosystem may in future come from within ESS, academic institutions, industry partners, or students. These people either have the scientific and technological knowledge to create new solutions or identify and validate a market need that can be solved fully or partially by ESS' and other complementary technologies. The employer of these innovative people, being ESS itself, universities, or established companies, will be responsible for building innovation capacity within the organisation and train these innovative employees by providing essential skills for technological exploration and market development and rewarding risk-taking innovation activities. It goes without question, that while these activities are crucial to ESS's future success, that much of this activity will take place once ESS moves into full operations. Like some leading innovative universities, **ESS may wish to consider entrepreneurship support a key function of the innovation board by allocating some proof-of-concept funding and helping connect internal entrepreneurs to relevant industry partners through the network of the industrial advisory board.**

Besides entrepreneurs emerging from within a stakeholder organisation, there are also *surrogate entrepreneurs* who come outside of the scientific research and development world around ESS but are experienced in starting up new business to address the gap of market that can be closed by new technologies (Nikiforou et al., 2018). They often bring along valuable business-related experience and competences to the network of researchers and established companies. The inclusion of surrogate entrepreneurs brings in a new element to boost the innovation capacity of the entire ecosystem. **ESS may consider connecting a wide range of surrogate entrepreneurs through the network of its innovation board and industrial advisory board and establish regular networking events to connect them with researchers, suppliers, and collaborating industry.**

13.3. For Funding Organisations

Current and future perspective of EU's research spending is expected to stay strong, especially among key Member Countries of ESS (e.g., Sweden, Denmark, France, and Germany) impact. Beside European level of research funding, there are also diversified funding organisations at the national level, providing funding to cover various types of research and different levels of development risks. The weakness so far is that the application process and procedure might be too complex and short-noticed with little chance for a single organisation or an inexperience group of partners to succeed. Current available innovation funds sometimes focus on too much moving forward towards higher levels of TRL for applied projects, with limited appreciation of the innovative capacity building for the stakeholder organisations. A potential threat could be that funding organisations tend to focus on the Green Transition Policy too-narrowly without realising the relevant of neutron science and related technologies so that funding will be misled to sustainable solutions instead of the science and technologies that eventually enable sustainable solutions.

To build on such strength and reduce the weakness, EU funding instruments and national level of call should be more precise to meet the needs of stakeholders in collaborative innovation processes. Here **ESS, as a prominent large RI in Europe, could play an influential role to showcase different mechanisms of collaborative innovation with academia and industrial users with evident cases so that EU funding instruments and national funding organisations will react to such clearly demonstrated needs and potential impact.** In the ESS Social Economic Impact Report and the BrightnESS² WP4 Deliverable report 4.2, there are many documented cases regarding innovations generated by academic and industry users, suppliers with support by ESS, ILOs, and other intermediary organisations. These cases should be made visible to funding organisations. This would benefit from dialogue among ILOs, ESS management, industry representatives from Member countries, and key influencers/policy makers of European and national science, technology, and innovation funding organisations. Funding organisations throughout Europe are keen to boost innovation capacity of their own ecosystems and some have explored **setting objectives and budgets for projects that create long-term impact push the boundaries of fundamental research and leverage complementary assets of collaborative partners among academia, industry, and public sector organisations**. Evidence is still emerging on the success of various approaches and ESS will wish to be fully engaged with LENS and others as they explore and optimise different approaches.

13.4. For Academia

Academia partners around ESS include In-Kind Partner universities and other collaborating academic institutions. The academic partners have *strength* in their deep scientific and technological competence and knowhow., which can be draw upon and co-develop when innovation challenges emerge. The diversity of ESS academic partners also ensures opportunities for cross-disciplinary innovation that move the boundary of scientific fields. Many university scientists also have dual affiliation to ESS. Academic partners should introduce formalised approaches to encourage and strengthen these favourable conditions by, for instance, **setting up a common interface for communicating and collaboration with ESS (**e.g., at Technical University of Denmark there is a network of scientists across departments, innovation officers and a dedicated dean to meet regularly to share information regarding ESS)**, supporting rewarding dual affiliation, and reward scientific work and joint proposals of grants resulted from the dual affiliation.**

However, there is a systematic *weakness* among academia regarding innovation – that is, from an innovation perspective, the focus on and priority made to publication may not lead to sufficient motivation to engage in innovation, technology commercialisation and entrepreneurship. Often universities and therefore scientists are driven by the first and second mission of universities (education and research, respectively) and missing the third mission (innovation and societal impact) so their ranks are not full of entrepreneurs. In some countries and universities, performance measures for scientists do not encourage engagement in innovation activities, let alone entrepreneurship. In addition, since the end of the 1990s, most European countries have been moving away from inventor ownership of patent rights (professor's privilege) towards different systems of institutional ownership, which means that the results of publicly funded research are often owned by the institution employing the researcher responsible for the work, instead of the scientist inventor. Denmark was the first country to decide, in 2000, to abolish professor's privilege in favour of institutional ownership, followed by Germany, Austria, Norway and Finland in the period 2001-2007. Such an IP rule might result in a lack of incentive to pursue innovation and entrepreneurship, if there is no fair mechanism of tech transfer to the inventor. To avoid the impact of this, an important recommendation is to **have a fair and transparent technology licensing agreement with the inventor and provide strong support to help the inventor with regard to technology transfer, commercialisation, patenting and even start-ups**. Meanwhile, **research departments should be encouraged to strengthen innovation performance as an integral part of researchers KPI to encourage cross-boundary collaborative innovation with external partners, such as ESS.** In addition, **in the cases of scientists having dual affiliation to a university and to ESS, ESS is recommended to carefully prepare a clear IP rule that not only complies to European and national IP regulation, but also provides strong benefits/incentive to the inventors by offering a corresponding set of patenting and technology commercialisation support**.

There is an enormous potential in engaging academics/scientists in innovation capacity building and there will be great impact and value in getting innovation recognised as a currency for science once ESS is fully operational. Several national-, and regional-level platforms have been established to support academic entrepreneurship. For instance, in ESS' hosting countries Sweden and Denmark, there are dedicated innovation foundation (Vinnova and Innovations Fund, respectively) to give grants to innovation projects that offer opportunities for university scientists, ESS researchers, and industry partners to collaborate. In Denmark, a project called "Open Entrepreneurship" (open-entrepreneurship-com) at the national-level connects all Danish universities and helps scientists to innovate, connecting entrepreneurs and established companies. We recommend that **ESS needs to**

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build closer relationship with these national innovation foundations and national academic entrepreneurship projects, making itself more visible by promoting successful academic-business impact cases. Moreover, **where innovation has been included as one of the KPIs for academia,** such institutional incentives must be reinforced and clearly recognised at ESS, especially for those who have dual affiliation.

The ESS' access route for academic users is being designed with an objective to ease the work of typical academic users as well as leverage their expertise to attract inexperienced industry users (see BrightnESS² Deliverable 4.4 Processes and Procedures for Targeted Access Routes). The access routes are designed and implemented to make good use of and further facilitate the innovation capacity of academic users, as well as expanding the scope for industry users. Innovation capacity building of the academic partners has strong implication for the innovation capacity of ESS and industry partners. One recommendation **to leverage this mutual benefit is to give flexible and favourable conditions to industry use of peer-reviewed access together with academic partner(s).**

13.5. For Corporate and Industry

Corporates and Industrial firms can play roles as suppliers, users, or collaborators. As *suppliers*, they react and proactively challenge the tender calls of ESS and push their technology boundary to make improved or new solutions. Industry suppliers found Big Science Business Forum (BSBF) highly relevant and demonstrated innovation and economic benefits from supplying ESS. There has been convincing evidence showing that supplying ESS creates positive innovation, economic and reputational benefits for the suppliers (see ESS Socio-Economic Impact Report 2021, BrightnESS² Deliverable 5.4). As *users*, they have great potential to utilise the power of neutron experiments to push forward research that create value for industrial applications. ESS has suggested new access routes and service catalogue for future industry users (see BrightnESS² Deliverable 4.4 Processes and Procedures for Targeted Access Routes and Deliverable 4.5 Service Catalogue including price list with three use cases). As collaborators, industrial firms co-invest in R&D projects that best combine knowledge assets of partner universities and ESS (see ESS Socio-Economic Impact Report 2021, BrightnESS² Deliverable 5.4).

Industrial firms that are associated with ESS have *strength* in their innovation capability and capacity, which have become the most important assets of knowledge-based companies. Other leading innovation companies, which have not yet worked with ESS but have benefited from collaborative innovation with Big Science Organisations have expressed early interest in ESS facilities. However, not all industrial firms are paying equal attention to the future benefits of working with ESS, due to different levels of experience and capacity of working with Big Science Organisations. Many SMEs are either unaware of or inexperienced with dealing with ESS due to lack of knowledge about business opportunities and procurement procedure (Li-Ying et al., 2021).

There are indeed emerging *opportunities*. Evidence is convincing that supplying ESS creates positive innovation, economic and reputational benefits for industry. There has also been convincing evidence that collaborative innovation relationship between ESS and corporates generates strong positive innovation and societal impact (see ESS Socio-Economic Impact Report 2021, BrightnESS² Deliverable 5.4). Moreover, ESS ILOs have focused on innovation and help industry suppliers to innovate along the needs of ESS (see BrightnESS² Deliverable 4.1 Report on the Evolvement Potential of ESS ILO network). Other intermediary organisations, for instance, the LINX project in Denmark and the LINXS platform in Sweden, facilitate collaborative R&D with ESS.

There are also factors that might be a *threat to* the participation of industry in innovation with ESS. For instance, innovation capacity building requires investment and time. These two elements are often threatened by quarterly profit/loss reporting and financial performant pressure in the short-term. In addition, if the economic return from supplying to ESS does not substantiate and direct impact on further innovation remains unclear, potential suppliers will not be incentivised to invest in innovation with and for ESS.

To mitigate the threats and seise the opportunities, ESS can help build the innovation capacity of industrial firms, paying special attention to helping inexperienced SMEs, under the management of the innovation board and the industrial advisory board by, for instance, **(1) easing the procurement procedure and engage suppliers as early as possible in the tendering process and often hold pre-tendering information events for industry, or even to invite suppliers to visit ESS - this can be supported by ILOs; (2) establishing and continuously updating a supplier database with the help of the ILOs; (3) using market intelligence to proactively scout relevant industries for new suppliers and support the pre-procurement ESS-supplier relationship; (4) dedicated personnel with knowledge in procurement and engineering technologies and well-trained about innovation strategy and process. This functional employee should not only be measured against procurement KPIs, but innovation KPIs; (6) establishing effective communication channel and information exchange mechanism between the innovation board and the industrial advisory board; (7) assign dedicated functional personnel to proactively explore the future industry users and collaborative partners among key universities. This function needs one (or more than one) person(s) with both academic experience and extensive industry experience in sectors relevant for neutron science.**

13.6. For Intermediary Organisations

The existing intermediary organisations within the ecosystem have several aspects of *strength*, of which ESS should continue to benefit from. For instance, the ESS ILO network was established back in 2013 to promote business opportunities to relevant industries in Member countries and create cross border collaboration. To do this In-Kind Field Coordinators have also been included as an important part of the network. The ILO network also contributed to the improvement of ESS' procurement system and a shared portal, which has been simplified to make it more transparent and simpler. The ILO network has held several meetings and workshops to align the goal of innovation both from within ESS and from the industry that supplies to ESS (see BrightnESS² Deliverable 4.1 Report on the Evolvement Potential of ESS ILO network and Deliverable 4.3 Cross-border activities). The strength of the ILO network provides opportunities for ESS and could be utilised by continued good communications among ILO officers and In-Kind field coordinators. **ESS may consider having a dedicated function of innovation office, which ILOs can directly engage** (see BrightnESS² Deliverable 4.1 Report on the Evolvement Potential of ESS ILO network)**.** Other national platforms (e.g., LINX in Denmark and LINXS in Sweden) have accumulated invaluable experience to boost collaborative innovation among public and private stakeholders. These national intermediary organisations complement the function of the ILO network, as the former focus on collaborative innovation among academia, industry *as users* and/*or collaborators*, and ESS, while the latter focus on innovation with industry *as suppliers* (see the difference in Li-Ying et al., 2021). **The strength of ILOs and national intermediaries can be amplified by having formalised contacts between the ILO and the leadership role of a national intermediary in a Member Country to close any potential information gap.**

There is also *weakness* among intermediaries. For example, the understanding regarding innovation and the level of focus on boosting innovation among industrial suppliers varies among ILOs in different Member Countries. This is also reflected in the fact that some ILOs lack capacity to prioritise innovation (see BrightnESS² Deliverable 4.1 Report on the Evolvement Potential of ESS ILO network). In addition, some national platforms are facing difficulty in receiving sustainable funding to keep the intermediary operating. Among the ESS Member countries, there is a lack of unified innovation strategies and coordinated efforts with regard to innovation by industry suppliers, users, and partners. **The impact of these weaknesses can be, to some extent, reduced by, strong leadership at ESS, continued dialogue among ILOs, ESS management, industry representatives from Member countries, and key**

influencers/policy makers within national Science, Technology and Innovation funding organisations, and promoting role model cases of successful innovation scenarios so that typical innovation path can be agreed on and followed.

Intermediary organisations face various future *opportunities*. First, the European Commission has been promoting *innovation procurement* as a key instrument to boost industry innovation pushed by public procurement. **ESS' procurement procedure and protocols should continue to follow the best practices of innovation procurement**. For example, **the ILOs seeking to encourage early involvement of multiple suppliers in the design and development of challenging innovation solutions for ESS as set out in the EU Commission's concept of Pre-commercial Procurement (PCP).** Second, the European and national policy towards **the Green Transition policy and sustainable development in general offers emerging opportunities to the intermediary organisations by linking potential applications of neutron science and technologies to sustainable innovative solutions**. Some national intermediaries, e.g., the Danish LINX Project, have extensive experience to set up simple feasibility test at the facility for industry users, an approach that minimises the work of both the inexperienced industry users and complements the human resources of the research facility. In the next years, **ESS might explore dedicating personnel to work closely with intermediaries to support the work of industry users so that the value of neutron experiments for industry will be optimised.** Finally, when ESS transitions into the Operations Phase, there will be **more opportunities regarding technology upgrading, for which the ILOs are liable to identify and help relevant industry suppliers to provide innovative solutions** (see BrightnESS² Deliverable 4.2 Strategic Roadmap for Technological Upgrades of ESS)**.** Special attention should be paid to helping inexperienced SMEs and Deep-tech start-ups.

The potential future *threats* can be mitigated by strategically **focusing on the collaborative innovation possibilities during technology upgrading** (see BrightnESS² Deliverable 4.2 Strategic Roadmap for Technological Upgrades of ESS) so that suppliers can be involved in the process as early as possible. This would require dedicated personnel at ESS – working with the innovation board - as well as full attention from the ILO network. With respect to the possibility of cross-national and national platforms being discontinued, jeopardising knowledge accumulation and sharing, **ESS should seriously assess the risk and its potential impact and lobby with national interest groups**, **including lead industry users and universities in relevant Member Countries, to secure next rounds of funding support**.

Careful readers might have already noticed that most recommendations to build innovation capacity for one type of stakeholder require support from, or have implications on, other stakeholders' innovation capacity. This is exactly why innovation capacity building can only be addressed using an ecosystem approach – all stakeholders depend on and collaborate with each other. Table 3 below summarises the main recommendations regarding innovation capacity building for each type of stakeholder and their relevance to other stakeholders. The relevance of each has been conceptualised into several categories: administrative and practical support, ad hoc collaboration, formalised collaboration, co-investment, and value-adding. *Administrative and practical support* includes activities of simple information sharing, personnel mobility, project registration, data availability, small expenses co-finance, etc. *Ad hoc collaboration* includes one-off collaboration on research and innovation project, for which costs can be shared by collaborating parties in their existing operational budget. This is an interesting mechanism because often discovery or breakthrough starts with a "try-out" based on curiosity without needing substantial funding (so-called "serendipity". Warenham et al., 2021). The positive result of ad hoc collaboration often leads to more formalised collaboration, which terms and conditions are agreed and institutionalised. *Formalised collaboration* also needs substantial funding. Compared to formalised collaboration, which usually needs third-party funding support, *co-investment* requires one more level of mutual commitment because it entails collaborating parties to commit resources as investment from their own financial pool. Co-investment does not exclude the significant role of risk capital to partake. The last type of mutual dependence is *value-adding*, which means one party's output serves as a decisive input for another party to create added value. This is typical in innovation procurement relationship where supplier adds value to the procurer.

Table 3 Mutual dependence and forms of cooperation among stakeholders to collectively build innovation capacity

	Mutual dependence and Forms of cooperation					
	ESS	*Entrepreneurs*	*Funding organisations*	*Academia*	*Corporate & Industry*	*Intermediary Organisation*
ESS	–					
Entrepreneurs		–				
Funding organisation	- Formalised collaboration - Co-investment	- Co-investment	–			
Academia	- Ad hoc collaboration - Formalised collaboration - Co-investment - value-adding	- Ad hoc collaboration - Co-investment - value-adding	- Formalised collaboration - Co-investment	–		
Corporate & Industry	- Ad hoc collaboration - Formalised collaboration - Co-investment - value-adding	- Ad hoc collaboration - Formalised collaboration - Co-investment - value-adding	- Formalised collaboration - Co-investment	- Formalised collaboration - Co-investment	–	
Intermediary organisations	- Admin and practical support - Formalised collaboration - Co-investment	- Ad hoc collaboration - Formalised collaboration	- Co-investment	- Admin and practical support - Ad hoc collaboration - Formalised collaboration	- Ad hoc collaboration - Formalised collaboration - Co-investment	–

14. Conclusion

European RIs play a crucial role in delivering scientific breakthroughs and fostering innovation to deliver real world results from *enabling science and developing high-tech*. Given the broad consensus on the need to address the societal challenges facing Europe and the world, RIs have an incredibly important mission to create and sustain innovative capacity as one route to deliver societal impact.

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In all aspects, RIs need to optimise their work to move scientific discoveries and technology forward "taking ideas from inception to impact". The more traditional measure of scientific impact, the number of publications - while important – will never be enough to measure or drive innovation.

ESS has already and will continue to enable new discoveries, excellent science and first-of-a-kind technology, which when applied to real-world challenges will change the world. ESS is a treasure chest of innovation opportunities and possibilities that can be unlocked by building innovation capacity both within ESS and out within its ecosystem. The description and recommendations in this report are meant to contribute to a new way of exploring and maximising the innovation potential of ESS.

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  - D4.1 Report on the Evolvement Potential of the ESS ILO Network (https://brightness.esss.se/sites/default/files/deliverables/D4.1Evolvement%20Potential%20of%20the%20ESS%20ILO%20Network.pdf)
  - D4.2 Strategic Roadmap for Technological Upgrades of ESS
  - D4.3 Cross-border Activities
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  - D4.5 Service Catalogue including price list with three use cases
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