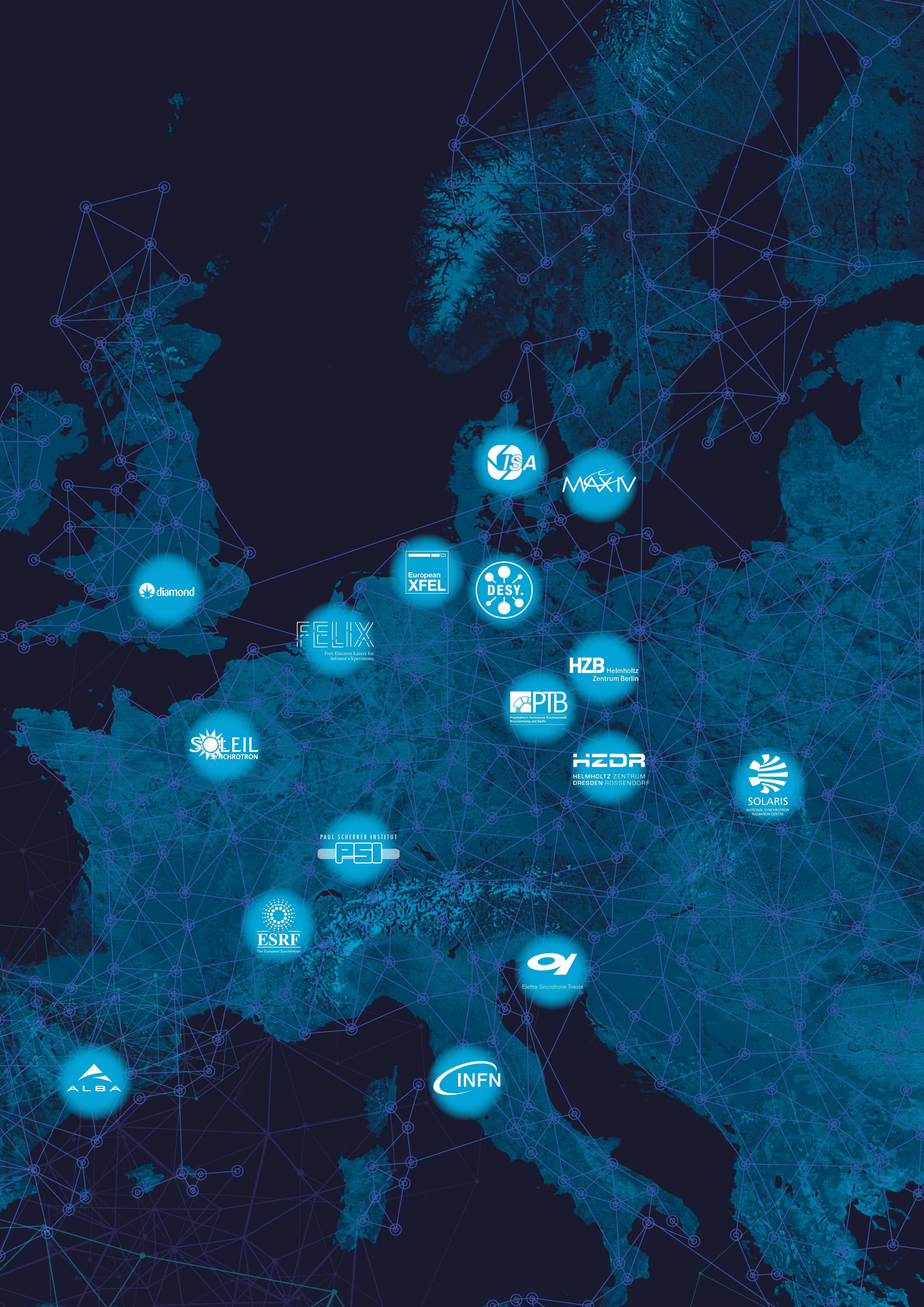
The European Strategy for Accelerator-based Photon Science

ESAPS 2022

LEAPS
League of European Accelerator-based Photon Sources

Content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ACCELERATOR-BASED PHOTON SCIENCE: STATUS AND DEVELOPMENTS ADDRESSING KEY SOCIETAL CHALLENGES

Accelerator-based photon facilities, i.e. high-brilliance synchrotron radiation facilities and free electron lasers (FELs), provide unique analytical tools for the destruction-free operando and in situ exploration of the molecular and electronic structure and processes in novel materials and biological systems. Today they are serving more than **35.000 researchers** at **19 highly dedicated facilitie**s situated throughout Europe and, serving all scientific disciplines from materials, drug design, biochemistry, health, catalysis, geosciences and planetary research to palaeontology and cultural heritage.

1.1 LEAPS foundation, ambition and strategic relevance

The European accelerator-based photon facilities joined forces in 2017 through the formation of the strategic European consortium LEAPS[1] (League of European Accelerator-based Photon Sources). LEAPS´ goal is to work collaboratively in a new strategic way, mobilizing the members' substantial expertise in photon science and technology, research infrastructure management and service to users and stakeholders. One of the consortium's ambitions is to be a driving force in the formation of European teams with competence in materials modelling, synthesis and analysis that can leverage the full potential of the LEAPS facilities in order to meet the needs of the scientific community.

LEAPS facilities are based on the most modern technologies available today and thus constitute a key component of the high-tech capability of Europe. They cover critical core competences for an advanced technological society, including precision instrumentation for IT as well as novel semiconductors and chip production methods.

The funding for the access to the LEAPS facilities is borne primarily by national funding agencies and has in the past also been supported by the European Commission ("Trans-national access, TNA").

During the years of the COVID-19 pandemic, the relevance of this new research consortium has become particularly visible, as all LEAPS facilities made available their experimental stations to virologists and hospitals for precision structural analyses. Among the future challenges we will have to solve in Europe, combatting vexing diseases and climate change will remain predominant issues. The unique analytical capabilities at LEAPS facilities in the molecular design of drugs and vaccines as well as of new materials for future carbon-free energy systems and for a future circular economy will therefore be of paramount European, even global importance.

1.2 Service provision for European researchers from academia and industry

LEAPS facilities offer open access to national, European and international researchers inviting curiosity-driven projects to be carried out as well as applied research projects, crucially enabling young investigators at the beginning of their career to exploit these high-tech infrastructures for their research. Access to the facilities is granted after a successful review process where the incoming proposals are rigorously ranked by excellence and relevance. LEAPS facilities provide over 1 million hours per year of user access to researchers from academia and industry.

The facilities are also made available to industrial partners free of charge, when the results are made public. In the case of proprietary research projects beamtime hours are charged to the industrial users.

The EU funded **CALIPSOplus**[2] project (ended 31 Oct 2021) aimed to remove barriers for access to world-class Accelerator-based Light Sources in Europe and in the Middle East. To this end, more than **179,000** hours of Trans-national access were provided by these research infrastructures and specific programmes were implemented to teach new users how to successfully use synchrotrons and FELs. Dissemination activities targeting industry were complemented by tailor-made support and access programmes for this user group. In parallel the consortium collaborated on constantly developing technology to keep the facilities at the cutting-edge. A future broad programme for curiosity-driven Trans-national access for all European researchers would continue enlarging the user community and their impact on European development.

1.3 Preparation of an infrastructure and technology roadmap

During recent years, the LEAPS consortium and its user community, which gathers the LEAPS Strategic Partner ESUO[3] (European Synchrotron and FEL Users Organisation), the national users associations, and the facility users' associations, have defined mandatory measures for improving the technical capabilities of the facilities in order to comply with the future needs of European researchers from academia and industry.

These include the following aspects as highest priorities:

- the upgrade of the storage rings with a revolutionary novel electron lattice based on the so-called multi-bend achromat technologies which delivers an unprecedented new level of brilliant radiation and the further development of the novel FEL facilities with emerging concepts (continuous wave operation, laser-seeding, new detection and computing capabilities)

[1] LEAPS – League of European Accelerator-based Photon Sources (leaps-initiative.eu)
[2] http://www.calipsoplus.eu/
[3] https://www.esuo.eu/

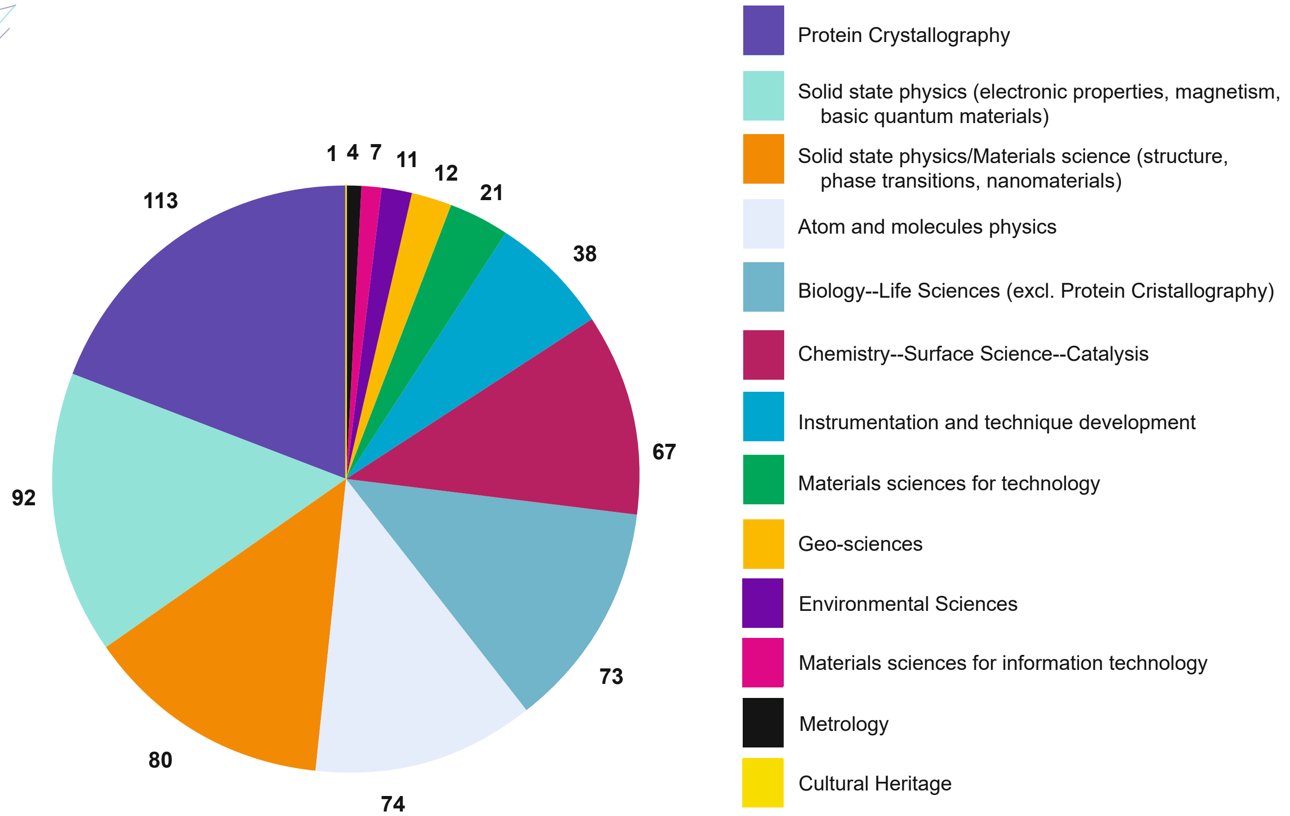


Fig. 1: Use of LEAPS labs for a broad science community. Example: number of publications at SOLEIL in 2018, by scientific field

The costs for the facility upgrades are substantial and are covered by the national funding agencies of the LEAPS facilities.

- the development of enabling technology encompassing advanced instrumentation for beam control and diagnostics; novel optics to preserve the beam quality during beam transport to the experiment; novel high-throughput sample delivery systems; advanced pixel detectors for highest data rate and in particular novel AI-assisted data handling and real-time simulation technologies

One aim of these upgrade plans is - against the background of climate change - to dramatically reduce facilities' electrical power consumption and reduce their carbon footprint.

Materials for the circular economy. A radical shift to the Circular Economy is urgently needed to cope with the challenge of finite resources decreasing at a frightening pace while the quantity of waste increases alarmingly. The European Commission´s Circular Economy Action Plan adopted in March 2020 has identified seven key product value chains that must rapidly become circular, given their environmental impacts and circularity potential. This requires substantial research on materials with a very high recycling capability while exhibiting competitive functionalities. Here, European analytical research infrastructures are joining forces to pioneer a support hub for materials research supporting the transition to the Circular Economy by offering coordinated access to Europe´s Accelerator-based Photon Sources and to more than 50 European analytical research infrastructures, comprising many of the facilities that constitute the Analytical Research Infrastructures in Europe (ARIE[4]) network. Again, LEAPS will join forces with research organisations and industrial partners to unravel key challenges.

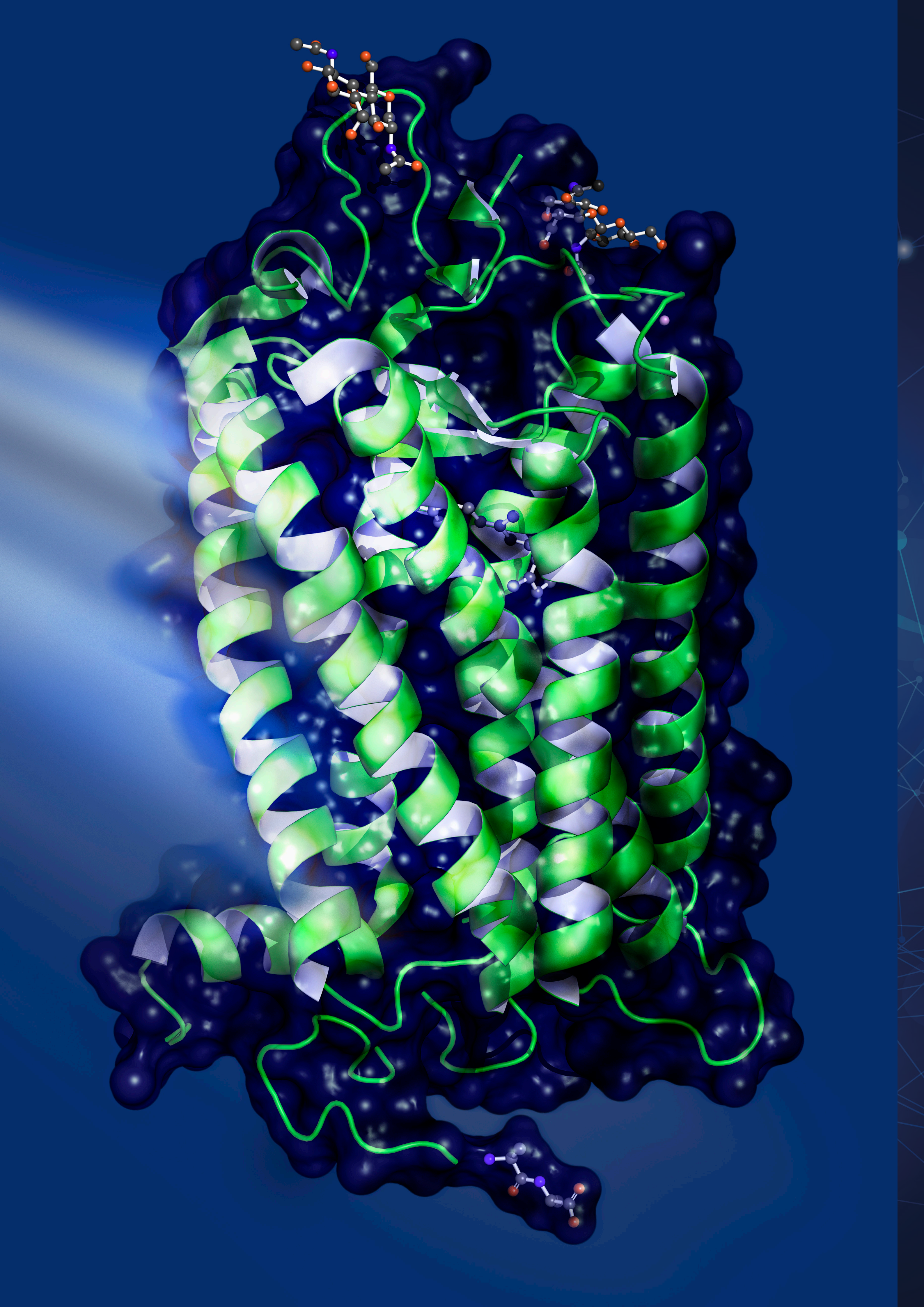
[4] Home - ARIE-EU

1.4 ESAPS 2022

The implementation of these extensive technology developments in partnership with researchers requires the formulation of a new European strategy for the further development of the research infrastructures and their future use.

The **European Strategy for Accelerator-based Photon Sources** as presented herein - ESAPS 2022 - is a coherent plan addressing the future challenges and needs of the new era in research and innovation, designed to put Europe in a global leadership position in this important technology of the future. It encompasses:

- the expansion of service provision to speed-up emerging research for societal challenges enabling new strategic long-term cooperation with European Partnerships (also increasing resilience)
- the coordinated upgrade of synchrotron radiation facilities implementing a disruptive high-brilliance electron lattice
- continuous development of FELs
- joining forces to enhance facility operation by implementing new digital technologies (an inclusive coordinated development of key enabling (AI-assisted) technologies will integrate all European stakeholders from academia and industry)



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ESAPS 2022 FOR FUTURE SERVICE PROVISION

The analytical infrastructures developed at the LEAPS facilities provide critical molecular information for the development of sustainable solutions in the fight against diseases, for the rational design of new materials contributing to the future circular economy and for new energy systems.

2.1 Future schemes of service provision

In order to exploit this potential in the future, to respond to the grand challenges and to the future needs of European researchers from academia and industry, the LEAPS consortium is expanding its service provision in the following ways:

a. We maintain the established **discovery-driven service provision** supporting and developing new, disruptive ideas:
The development of a new generation of sources, dramatically more brilliant, enabling high-throughput spectroscopic and structural characterization fully integrated using AI methods in materials synthesis workflow together with simulations, **has the potential to tremendously accelerate the discovery process,** when leveraging the transformative upgrades, instrument developments and the establishment of powerful partnerships with the European researchers. Importantly, any investment at the facility level benefits all the above challenges making it the most cost-effective way to supprt mission-driven research to-date.

b. We implement a **targeted challenge-driven service provision**:
The first amendment[5] of the LEAPS declaration of 2017 states that its facilities are open to strategic access by large European partnerships and initiatives which address Horizon Europe missions[6] and require tailor-made access to LEAPS facilities for carrying out their long-term ambitious research projects. The large projects and research consortia stand to benefit from a well-established peer-review process at the LEAPS facilities that guarantees the highest standard of scientific excellence. As already tested by some facilities, going further can be achieved by providing dedicated beamtime, introducing specific criteria in the proposal selection process, and will require building or expanding expertise in those communities via for example, joint appointments of early-stage researchers.

We have identified, in particular, batteries, materials for the circular economy, public health challenges, rational catalysis design, green hydrogen, water-based technologies, and advanced materials as research areas where LEAPS facilities can make an impact.

Battery 2030+ initiative[7]. To achieve efficiency, reliability, and resiliency in energy storage technologies, a disruptive new level of understanding and control of the battery architecture must be reached. LEAPS facilities are well positioned to address all major challenges of the battery characterization aspects. LEAPS proposes a new handshake between European laboratories, European high-performance computing centres, and European analytical facilities to achieve new levels of electrochemical performance for next generation batteries. This should be coordinated with the involvement of key European industrial stakeholders to strengthen industrial leadership through accelerated research and innovation in a global race. The LEAPS consortium thus strongly supports the “BATTERY 2030+”-Roadmap and is prepared to play its role in this pan-European effort to devise tomorrow´s batteries. Again, LEAPS will join forces with research organizations and industrial partners to unravel key challenges.

c. We develop a new **remote service provision**:
An integral part of LEAPS’ European strategy includes the enhanced automated operation of experimental schemes, remote access for users, including on-line data analysis in near real time to guide an ongoing experiment.
The ambition is a noticeable reduction of the carbon footprint of user operation (by reducing unnecessary travel) and the integration of new international collaborations in new ways. It also improves accessibility and resilience of RIs during crisis periods with restricted mobility.
As a lesson learned from the Covid-19 pandemic, LEAPS has recently implemented an internal project Digital LEAPS² (see more chap.4) to coordinate further developments toward new remote access schemes including AI-assisted robotics and virtual user experiments. This will boost the impact Accelerator-based Photon Sources in all dimensions ranging from targeted challenge-driven and discovery-driven science to novel industrial use and the new schemes of outreach and education & training.
To implement remote service requires resource provision and strategic planning. To this aim, LEAPS has initiated and taken over the leading role in the Horizon Europe project (eRImote) to explore digital and remote service provisions across analytical RIs taking steps beyond the state-of-the-art for concrete solutions.

2.2 Addressing future strong partnership pilots with targeted challenge-driven service provision

“Accelerating research for Health and for a Clean Planet”

In the coming years, LEAPS sees its role particularly in strategic collaboration with leading European players aiming at accelerating research for Health and for a Clean Planet. The new strategic access to LEAPS facilities will

[5] Consortium Declaration (leaps-initiative.eu)
[6] PostionPaper_HEMissions_March2020.pdf (leaps-initiative.eu)
[7] LEAPS-Battery-Roadmap2030.pdf (leaps-initiative.eu)

Pilot projects on advanced catalysts should include:

- **Creation of cross-facility/cross-technique platforms for in-situ/operando characterization of catalytic materials and processes bringing together academia and industry**
- **Foster collaboration with industry by implementing new access schemes and integrated service provision, including digital services, remote access and automation**
- **Development of lab-scale reactor demonstrators as starting points for industrial up-scaling**

allow European partnerships to have **new opportunities for targeted collaborations in the areas of:**

- **Public health**
- **Rational catalyst design**
- **Green hydrogen**
- **Clean water**

Public health

During the COVID-19 pandemic, Accelerator-based Photon Sources swiftly joined forces by offering their capacities to the scientific community by opening calls for rapid access to dedicated beamtime for COVID-related projects aiming at understanding the disease, therapy, and vaccine development. Accelerator-based Photon Sources thus significantly contributed to minimizing the time from proposal to sharing new molecular insights with the scientific and medical community through publication and the development of therapeutic approaches. Boosting existing capacities with adequate national and European funding programmes, places Europe´s Accelerator-based Photon Sources in a strong position to be a major player in addressing public health challenges such as cancer, neuro-degenerative diseases, resistance to antibiotics, or the emergence of infectious diseases. Preventive medicine will also need a wider range of topics to be addressed, such as food science, absorption of vitamins and minerals, which are possible to explore using Accelerator-based Photon Sources.

A growing population demands more food, in particular food that meets the nutritional requirements of both the elderly and children, whose health is particularly dependent on their diet. Food production needs to reduce its environmental footprint and can be dramatically affected by conflicts like the one presently unfolding in Ukraine. The currently ongoing LEAPS facility upgrades will significantly increase the imaging and spectroscopy capabilities on the different length scales, greatly benefiting this field[8].

Supporting Europe in the development of climate-neutral technologies

Europe aims to be carbon-neutral by 2050, with an economy with net-zero greenhouse gas emission. Achieving this goal is at the heart of the European Green Deal which includes strategies for energy storage and transport, de-carbonization of industrial processes, and a more frugal circular economy. All these objectives imply the development of disruptive technologies requiring the efficient design of new materials as well as a new level of understanding of chemical processes. The LEAPS strategy proposes to establish strong partnerships with large academic and industrial networks to tremendously boost the discovery process and support European industrial competitiveness.

Advancing rational catalyst design

Catalysis contributes to one-third of the world's gross national product. It is key both to the production of green hydrogen (see below) as well as its conversion, together with sustainability sourced carbon dioxide, into liquid or gaseous energy carriers, and therefore essential for the decarbonization of the economy. The knowledge driven design of novel, environmentally friendly yet better performing catalysts requires a multi-modal approach combining chemical with biochemical approaches. This requires a number of different characterization techniques such as, for example, X-ray and light spectroscopy as well as electron microscopy and advanced numerical modelling ("digital catalysis"). Most importantly, as catalysis and bio-catalysis are dynamic processes whose active centres are formed or transformed under reaction conditions, both experimental and theoretical investigations have to be performed under in situ / operando conditions, i.e. under realistic reaction conditions. Europe´s Accelerator-based Light Sources provide the most powerful and unique platforms worldwide to address these challenges for both chemical and biochemical catalysis. Involvement of industry from the very beginning is essential for the choice of relevant materials and processes and an efficient scale-up to industrial dimensions.

Developing future clean hydrogen technologies

The hydrogen strategy for a climate-neutral Europe issued by the European Commission in 2020 emphasises that hydrogen can be used as a feedstock, a fuel or an energy carrier and energy storage with many possible applications across industry, transport, power and buildings sec-

[8] PostionPaper_HEMissions_March2020.pdf (leaps-initiative.eu)

tors. A clear advantage of hydrogen is that it does not emit CO_2 and almost no air pollution when used, thus offering a solution to decarbonize industrial processes and economic sectors where reducing carbon emissions is both urgent and hard to achieve.

We aim at establishing a close relationship with the Clean Hydrogen Partnership in order to find solutions for the optimization of industrial processes and the development of materials for a clean hydrogen economy at all stages in the hydrogen value chain from production and storage to the efficient synthesis of hydrogenated compounds.

Clean water

Water is the most critical natural resource on our planet, it also plays an important role in many future technologies. To take advantage of these water-based technologies, critical processes must be better understood at the microscopic level:

- Electrochemical or photoelectrochemical processes that involve water are central for the development of sustainable, CO_2-free energy storage and usage. Key examples are hydrogen production via (photo) water splitting in electrolyzers and the reverse conversion back to electrical power using fuel cells.
- Several large-scale applications require the development of membranes with advanced functionalities, whether for use in catalysis, (medical) water filtration, water remediation (decontamination of toxic water residues), water analysis (detection of macromolecules) or desalination to produce drinking water.
- Similarly, water in nanoporous materials plays an important role in energy systems for the storage of heat by means of reversible water vapour adsorption or water-based chemical reactions.
- Both the EU Green Deal and the UN Sustainability Goals recognize water pollution as a major threat and aim to bring about transformation. Tailored materials can be exploited for sustainable water purification and element harvesting starting with natural water sources, waste and process waters. These processes can result in (i) the production of safe drinking water and/or (ii) enrichment of highly demanded elements (such as lithium, germanium, indium, and rare-earth elements) that are inherently needed for modern technologies, such as in the communication and battery industry sectors. Removal ("harvesting") of these elements, which can then be fed into value chains contributing to the concept of the circular economy, results in cleaner drinking water. Other novel materials contribute to energy-efficient and safe drinking water production, such as desalination, denitrification as well as the removal of so-called "forever chemicals".

Pilot projects on water-based technologies should include:

- **Creation of sample environments and protocols for operando characterization of membranes for separation, purification, and strategic-element harvesting**
- **Development of procedures to characterize water properties in nanoconfinement at all relevant time and length scales**

In situ inspection of advanced and quantum materials

Advanced manufacturing and quantum technologies hold the promise of providing materials-based solutions for a more sustainable, circular economy and to make use of quantum effects for vastly increased sensitivity. Progress is tightly connected to combining materials knowledge with production procedures and devices fabrication. Primary objectives are movies of 3D advanced manufacturing and quantum computing processes in action.

To reach in situ inspection of materials, an integrated approach will be needed in the form of targeted campaigns that progress step-by-step from material characterization to in situ inspection. These challenges can be uniquely addressed via synchrotron-based experiments of the basic materials which then set the stage for examination of the dynamics at synchrotrons and X-ray FELs.


30 mm

3

ESAPS 2022 FOR FACILITY UPGRADES

Minimizing the ecological footprint has become a mandatory criterion for constructing new photon sources or upgrading them.

3.1 Facility upgrades

In order to tackle the societal, scientific and economic challenges outline in the previous section, LEAPS members are committed to working in a coordinated manner thereby enhancing European competitiveness and integration as well as extending its global outreach.

There has never been a more important time to upgrade facilities in a joint manner, both because of the urgency of the societal challenges themselves, and the massive investment that is boosting the performance and delivery of such facilities elsewhere in the world.

In the past decades many European countries have built Accelerator-based Photon Sources using the most advanced technologies known at that time[9]. Due to the experience gained during the operation of the storage rings and the improved technological capabilities of the facilities and industry, a revolutionary upgrade of the storage ring layout as well as the photon beamlines has been initiated at MAX IV (Sweden, Lund) with the multiple-bent-achromat (MBA) technology followed by the ESRF (France, Grenoble) with a new hybrid multiple bent achromat (HMBA) technology. These two facilities have reached an unprecedented level of photon beam brightness and degree of coherence, allowing new types of experiments. These achievements have prepared the ground for a further upgrade programme of many of the national-based storage rings in Europe (see following figure 2) and have positioned Europe at the front of this technology. The innovative layout has been recognized internationally; the leaders of the projects won prestigious prizes in accelerator science.
The FEL facilities are internationally at the forefront of technology and science. Nevertheless, new projects and upgrades are envisaged for the next decade enhancing their capabilities as well as introducing new accelerating schemes providing ultrashort, phase-locked X-ray beams. The details of the upgrade plans by the different facilities will be featured at a focus point issue recently approved by European Physics Journal Plus, wherein each LEAPS facility will contribute with an invited paper.

ESAPS will be implemented as an open innovation effort in strong collaboration with industry stakeholders who are aiming to extend their product portfolios and markets. Their participation will certainly boost innovative industrial research and improve their competitiveness in the global market.

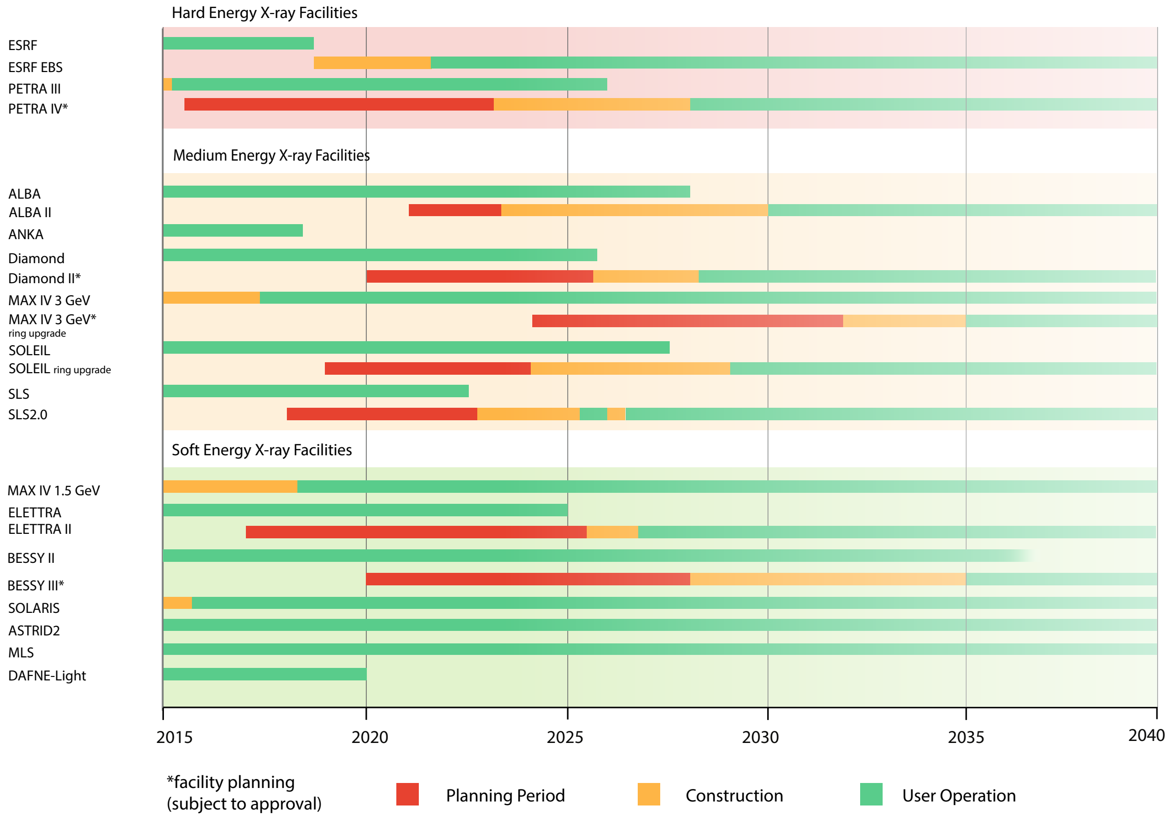
3.2 Green LEAPS: How facility upgrades reflect the European Green Deal goals

The operation and use of LEAPS facilities is very energy consuming. Therefore, during the preparation and realization of the upgrade programmes particular attention was given to the improvement of the operation of the facilities towards a more efficient use of energy and to reduce the carbon footprint overall. The development of permanent magnet technology helps to design storage ring elements with a very low consumption of electricity; the working conditions of accelerator components could be optimized lowering the amount of cooling water needed and the heat produced by them can be recycled as well.
The experiences gained during the pandemic situation have forced the organizations to develop an efficient "remote operation mode" for beamlines dedicated to research focused on projects relevant to COVID-19, whereby the users were able to perform measurements from their home institutions supported by local contacts. Remote operation mode can also be developed for standardized measurements in other areas, applying artificial intelligence and machine learning algorithms as appropriate. Remote operation mode allows a significant reduction of travel by users of the facilities while keeping the scientific output at a high level but it requires additional staffing at the facilities.

A concerted effort from the existing and planned European SR and FEL RIs to coordinate upgrades and developments will guarantee Europe its leadership in X-ray science and technology for the forthcoming decades.

[9] LEAPS_Landscape_Analysis_27March2019_final.pdf (leaps-initiative.eu)

Storage Rings



Free Electron Lasers

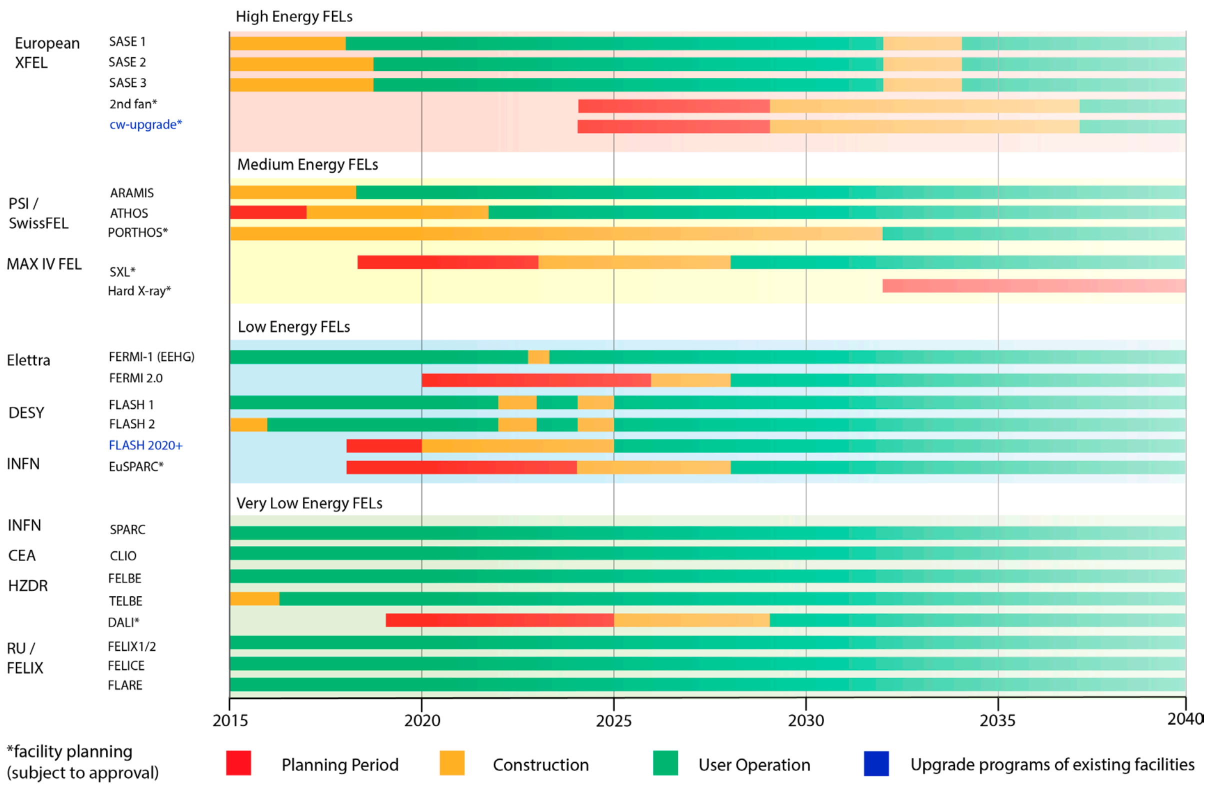


Fig. 2: Timeline of existing storage rings and FEL facilities, approved upgrades and plans for upgrades not yet approved (marked with an asterisk*), latest update Feb 2022

Enhanced remote operation allows a significant reduction of travel by users of the facilities while keeping the scientific output at a high level. New schemes of this "remote operation mode" can also be developed for standardized measurements in other areas. The application of artificial intelligence and machine learning algorithms have to be developed. This is an area that could be greatly boosted by new calls within Horizon Europe.

The following measures will be taken up to reduce LEAPS carbon footprint within the next years:

- purchase only renewable electricity
- use of permanent magnets
- waste heat recycling
- enhance remote operation
- optimize travel plans to minimize their carbon footprint, pay CO_2 compensation or roll out other related actions

3.3 Key enabling technologies

Synchrotron radiation RIs are currently currently taking a leap to the next generation of storage rings, generating X-ray beams of ultimate brilliance. Brand new RIs such as MAX IV or the powerful EBS upgrade of the ESRF are the first examples of this revolution, which has been conceived and launched in Europe and is now setting the agenda worldwide. The novel FEL RIs are opening new avenues to explore the atomic and molecular machinery of materials and biological architectures. There is a global scientific understanding that the clever interplay between both types of X-ray sources and the proper coordination of efforts will cover all the future needs of academic and industrial users in this field.
It is the ambition of LEAPS to orchestrate the future developments of its RIs via an appropriate roadmap process.
Unleashing the full potential of the LEAPS RIs will require substantial new developments for the entire technology chain, linking the photon sources, X-ray optics and diagnostics, experimental environments and positioning, detectors, software, and data management. Due to the complexity of the required technologies, this can only be achieved efficiently by a coordinated effort among the European Accelerator-based Photon Sources in cooperation with European partners, at universities, research institutes or related industries.

Photon sources

The evolution of the LEAPS landscape shown above rests on several on-going technological advancements.
In the case of synchrotron sources, the recent development of MultiBend Achromat (MBA) lattices, allowing a dramatic increase of photon beam brilliance and coherence, is pushing the advances in several accelerator systems. For example, in the use of permanent or hybrid magnets for green facilities; the related vacuum technology; new Insertion Devices extending the photon energy range and tunability; advanced instrumentation for beam control and diagnostics; Radio Frequency acceleration systems with new functionalities.

The funding of the different facility upgrades is supported individually by national governments. However, the possibility of common developments under the European umbrella will make the process much more cost and technically efficient, strengthening the world-leading position LEAPS members have had so far in the development of the field.

FELs' key challenges are better control of spectral and temporal properties to match the requirements for extreme time resolution (attosecond), high repetition rates, better time synchronization with external lasers, increased peak intensity and improved longitudinal coherence. The corresponding fields of research focus are the integration of the FEL sources with the experiments under these conditions; novel concepts for the control of FEL light properties; cavity based FELs; refined electron beam control. A longer-term goal is the development of compact sources based on plasma wakefield acceleration to make some of the capabilities of the current RIs available for industrial applications, hospitals and smaller laboratory environments.

X-ray detectors

X-ray detectors are a key enabling technology for developing new science and methods, and thereby contributing to the grand challenges society faces at present. Modern and state of the art technologies, including innovative sensors for detection, advanced microelectronics for signal processing, integrated silicon photonics for high speed data transmission and advanced materials for system integration, allow for the construction of next generation of X-ray imagers with performances matching the exponential development of X-ray sources. However, since the scientific applications are very diverse, and the detector systems need to be customized for different applications and energy ranges, many different systems need to be developed. This can only be done by a coordinated and distributed approach over the facilities in Europe. Systems that need to be developed include: continuous megahertz imagers, energy resolving imagers, low energy images, imagers with sub-micron spatial resolution. All these imagers need to have built in intelligence in order to cope with the enormous data rates.

X-ray optics

X-ray optics are key for efficiently transporting and tailoring the X-ray beam to and from the sample. With present technologies these optics degrade the intrinsic beam quality and hence the beamline performance. This is particularly prejudicial for scientific applications needing to exploit the beam coherence or attain nanometre scale spatial resolutions. Coordinated efforts are required to develop the new and improved optical devices capable of delivering the full potential of the X-ray sources to the user community.
Targeted actions are required to address the following topics:

- Optical material quality and processing methods – particularly with regard to surface engineering, structuring and figuring of optics
- Position accuracy, vibration and drift of opto-mechanical systems
- Deformation of optical components due to mounting and/or heat load
- Optical degradation and thermal fatigue following prolonged X-ray exposure
- Expert systems to optimize optical system performance in-situ

Sample environment

The wide variety of research activities at photon sources requires a diverse range of highly specialized sample environment equipment tailored to specific experimental challenges ranging from very fast timing capabilities to extremes of pressure or temperature. Furthermore, new generation sources will provide higher photon fluxes and smaller beam sizes increasing requirements on spatial and temporal accuracy while automated rapid sample exchange will become a requirement. In order to facilitate and enable pan-facility access to beamlines for both academic and industrial users, standardization of equipment and sample interfaces will be crucial. This standardization will be further extended to the data collected with both raw data and meta-data being recorded in a FAIR manner. In particular, standardized sample environment equipment for in situ and operando investigations in electrochemistry and catalysis will be crucial for high impact research related to clean, affordable and secure energy, sustainable and smart mobility, as well as zero-pollution and toxic-free environments.

A central element for the realization of the proposed upgrade plans relies on an enhanced readiness of European industries to match the challenges in the next decade. Some of the key technologies are only available at institutions outside Europe.

The LEAPS process to devise technology roadmaps, to prepare open calls for selected collaborative projects and to monitor their implementation is shown in Fig. 3. After an international benchmarking, the technology landscape analysis carried out by LEAPS will yield the mid-term (5 years) and long-term (10 years) LEAPS Technology Programme. This programme will constitute the framework for bi-annual action plans, with the aim to fund collaborative technology projects every 1–2 years via open calls. Open calls will enable the participation of stakeholders outside of LEAPS (e.g. industrial partners), which are vital in order to push forward the development of specific technology. One goal of these open calls is to support cutting-edge technology to unleash the full potential of the LEAPS RIs and promote smart specialization.

Within the frame of Horizon Europe, funding schemes to RI networks should be implemented with the aim of strengthening technological developments and production in a strong partnership with European industries and to reinforce European technological resilience.

RI technology proposals should address the developments of:

- **new and improved optical devices capable of delivering the full potential of X-ray sources**
- **customized detector systems for different applications and energy ranges**
- **hardware components for the handling and analysis of high data volumes**
- **insertion devices as well as permanent magnet technology**
- **nano-positioning and mechatronics**

3.4 Smart specialization and European cohesion

For this aim, LEAPS has launched a comprehensive analysis of the critical mass of specific expertise in key technologies currently developed in the LEAPS facilities (Fig. 3). The expertise encompass the development of new schemes in X-ray detectors, X-ray optics, dedicated sample environments, photon source development and information technologies. The colour code gives indications of the amount of resources dedicated to the R&D at different facilities. The smart specialization process described will benefit users throughout Europe who will have access to more advanced and complementary techniques at the facilities.
Figure 3 shows the survey results of existing competences of the LEAPS laboratories.

The implementation of key enabling technologies will envisage new avenues for smart specialization integrating all stakeholders across Europe thereby also contributing to the European cohesion process. This includes complementary solutions and specialised European consortia in high-tech developments.

3.5 Actions towards open innovation and to foster cooperation with European industry

ESAPS 2022 addresses the increasing complexity of advanced technologies and their shorter life cycles as key features which require the Accelerator-based Photon Sources to open up innovation routes to their partner facilities, users and industrial suppliers.
ESAPS 2022 aims to engage with industry even more deeply, both as a supplier and as a user, to keep Europe at the global forefront of competition on innovative technology development. ESAPS 2022 seeks exchange with industry experts for critical strategic guidance in the development of new technologies and by exploitation of technologies. At the same time this offers opportunities for industry to engage in research at LEAPS facilities, which is the most appropriate means for promoting and implementing such opportunities.
In addition, LEAPS can contribute to increasing the innovation and competitiveness of industry, identify industrial research priorities that will contribute to the strategy of LEAPS, consider other creative ways in which LEAPS can catalyse, nurture and capitalise on a higher level of cooperation with industry by developing new technologies for the future facilities as explored in the LEAPS-INNOV project.
The technology roadmap developed by LEAPS will be realized in partnership with industry. This will strengthen the companies already delivering to science facilities, as in the on-going LEAPS-INNOV pilot project, allowing them to take a bigger share of the global market.
The LEAPS technology-driven tasks will undoubtedly generate new ideas and technologies that can be commercialised, as well as existing advanced instrumentation at the photon sources. But a gap remains between the developers and potential commercial exploitation. LEAPS will close this gap to enable a more efficient transfer of technology to the market. A key example is DECTRIS[10], a spin-off from the Paul Scherrer Institute (PSI), now exploiting pixel detector technology for the wider global market. Technologies identified in the LEAPS roadmaps and offered to industry will also have an impact on other areas of the scientific market.
LEAPS has significant procurement needs and seeks to share and harmonize best procurement practices, focusing on innovative procurement procedures, targeting a wider supply chain and opening markets for European technology firms.

The **LEAPS-INNOV** project[10] is a first step to open innovation which will contribute to solving key technological challenges for light sources, over 50 facilities in Europe and worldwide, and in particular will support their newest generation - diffraction-limited storage rings and X-ray FELs. It will kick-start the implementation of the LEAPS Technology Roadmap and, at the same time, will enhance partnership with industry through open innovation by offering joint technological developments and advanced research capabilities for industry as collaborators, suppliers and users. In the context of open innovation, LEAPS-INNOV focuses on new approaches for partnership between industry and the photon science community, with the goal of accumulating a strategy for long-term industry engagement for LEAPS in Europe.

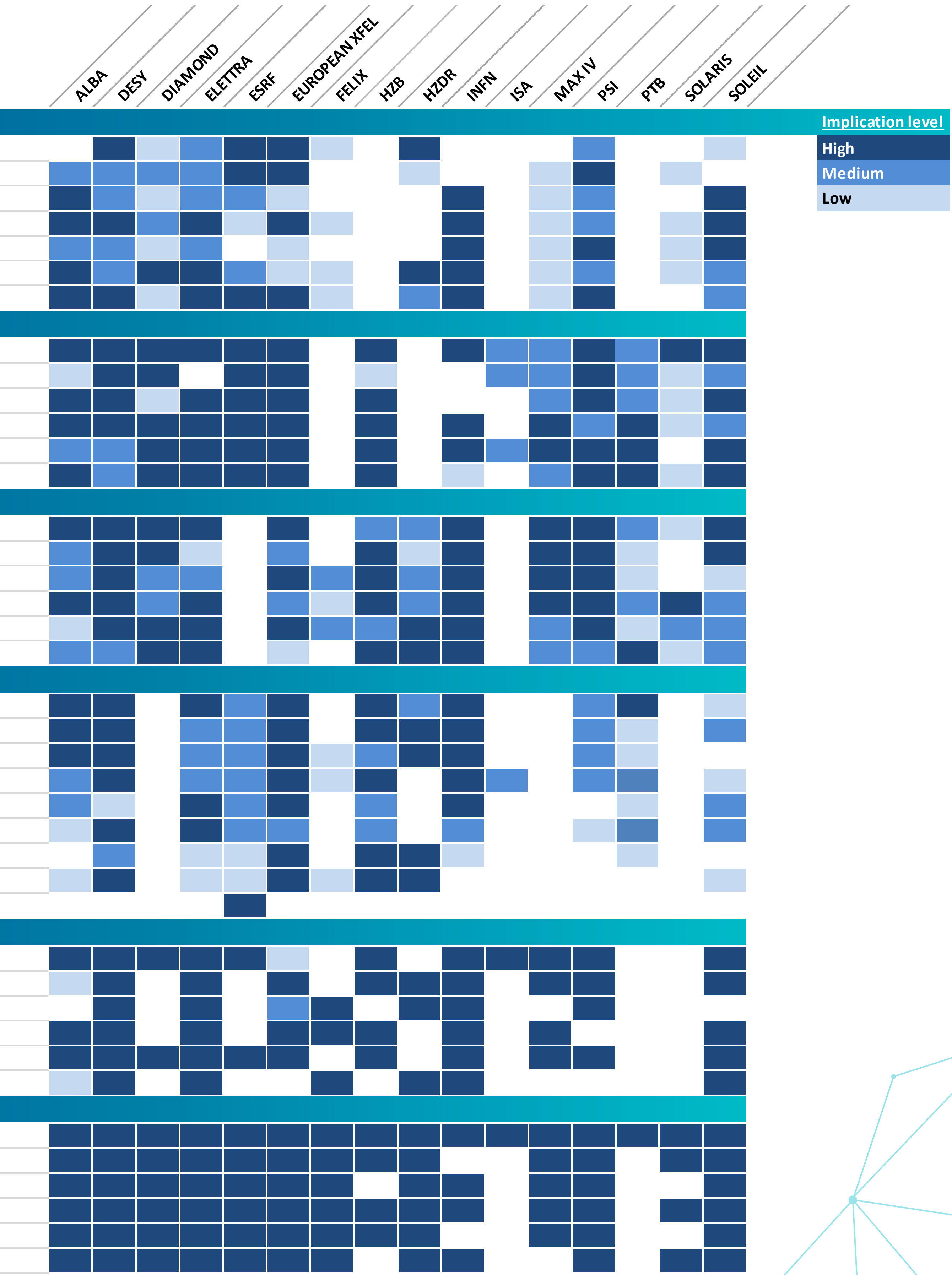
[10] https://www.dectris.com/
[11] Home | LEAPS-INNOV - Open innovation

LEAPS Technology Pillars

LEAPS Lead partners:

Fig. 3: Skill set of LEAPS facilities within the six LEAPS Technology Pillars

Detectors
Ultra-high continuous frame rate imager (> 10^5 frames per second with >10^7 pixels)
Small pixel imager (< 10 micron pixels, with > 10^8 pixels)
Large format and high flux energy resolving imagers (≥ 500 cm2; DE/E < 0.04)
Soft X-ray imager (50 – 2000 eV photon range)
Tender X-ray imager (500 – 5000 eV photon range)
High-speed multi-element spectroscopy detector (> 100 elements, >10^6 cps/element)
Common Toolbox (back end electronics and interface with computing system)
X-ray Optics
Reflective Optics
Refractive Optics
Diffractive Optics
Optomechanics, nanopositioning and thermal management
Simulation and modeling
At-wavelength metrology and test facilities
Sample Environment
Nanopositioning
High throughput sample environment equipment
Extreme conditions
In-situ / operando sample environment equipment
Time dependent experiments
Standards for sample environment control, data & metadata
Photon Diagnostics
Intensity monitors for EUV, Soft and Hard X-rays
Beam position monitors
Pulse length measurements
Polarization measurements
Energy spectrometers
Wavefront sensing
Automatisation for 24/7 operation of online diagnostics
Machine learning approaches to automatically optimize and stabilize the machine as well as the beam transport
Bunch purity measurements
Photon Sources
High field small aperture magnets and related vacuum technology
High brilliance electron beam production and control
Specialized laser systems for electron beam production, FEL seeding and plasma acceleration
RF acceleration systems
Advanced instrumentation for beam control and beam diagnostic
Joint R&D on compact plasma accelerator for photon science (context EU design study EuPRAXIA)
Information Technology
Governance, Education and Training
Open Data Policy for Open Science
High Speed Data Acquisition
Data Analysis and Reduction
Federated Data Catalogue
Generalization of the use of Cloud Services


ALBA
DESY
DIAMOND
ELETTRA
ESRF
EUROPEAN XFEL
FELIX
HZB
HZDR
INFN
ISA
MAX IV
PSI
PTB
SOLARIS
SOLEIL
Implication level
High
Medium
Low

4

ESAPS 2022 FOR THE DIGITAL TRANSFORMATION OF THE OPERATION OF EUROPEAN USER FACILITIES

"Devising a resilient and low-carbon operation of accelerator-based photon facilities"

ESAPS 2022 charts a route into the future that features new digital and environmentally friendly technologies and concepts while making a critical contribution to keep Europe at the international forefront of science and technology.

4.1 Development of advanced digital technologies

For the future, LEAPS facilities need to ensure they become even more resilient to times of crisis, where massive constraints on operations and mobility pose a challenge.

Resilience requires a fundamental reconsideration of user operation including remote operation tools and artificial intelligence concepts in the entire power train of the experimental installations from the accelerator to big data handling. Calls within Horizon Europe could boost this area greatly.

The DIGITAL LEAPS (DL) initiative aims to develop digital technologies to increase together, on a European level, the resilience of the LEAPS facilities by a fundamental reconsideration of user operation, including remote operation tools and artificial intelligence concepts. This will happen on a start-to-end basis, in the entire power train of the experimental installations from the accelerator to big data handling.

LEAPS has identified the strategic elements for a transition to a Green DL, to be implemented via three pillars addressing respectively technologies for advancing remote services (Surveying Technology for Advancing Remote Services, "STARS"), enhanced digital platforms for networking and training (Human Resources 4.0, "HR4"), more resilient green sources and beamlines (LEAPS Integrated Platform, "LIP"). The guidelines are to provide robust and resilient operation for the scientific community, at the same time audaciously pursuing the Green Deal goals and Europe's ambition to become climate neutral by 2050. Thanks to DL, we will become more resilient and at the same time we will explore the opportunities to create green facilities including circular economy aspects and interactions with industry.

The DIGITAL LEAPS initiative pursues the development of a digital interface system to access and autonomously operate green facilities, via digital twin, artificial intelligence and machine learning, virtual diagnostic, androids for remote access, and the design of further photon instruments for remote access and standards for fully automated user beamlines. This will be pursued along with the establishment of a digital collaborative platform (Innovation Mall), and platforms for remote training of staff and hybrid training for users. Finally, the aim is to develop a collaborative platform to create a smart user network, with tight connection to industry.

The above-mentioned initiatives are tightly connected with a pathway to more green operation of the LEAPS facilities. Digital remote user operation is going in the direction to rationalize the movements of people and the negative impact on the environment. At the same time, it will open up new access possibilities from geographically far countries e.g. Africa or Latin America. Smart user network and digital collaboration platforms will multiply the possibilities with common developments in the areas of environmental and neutral climate challenges.

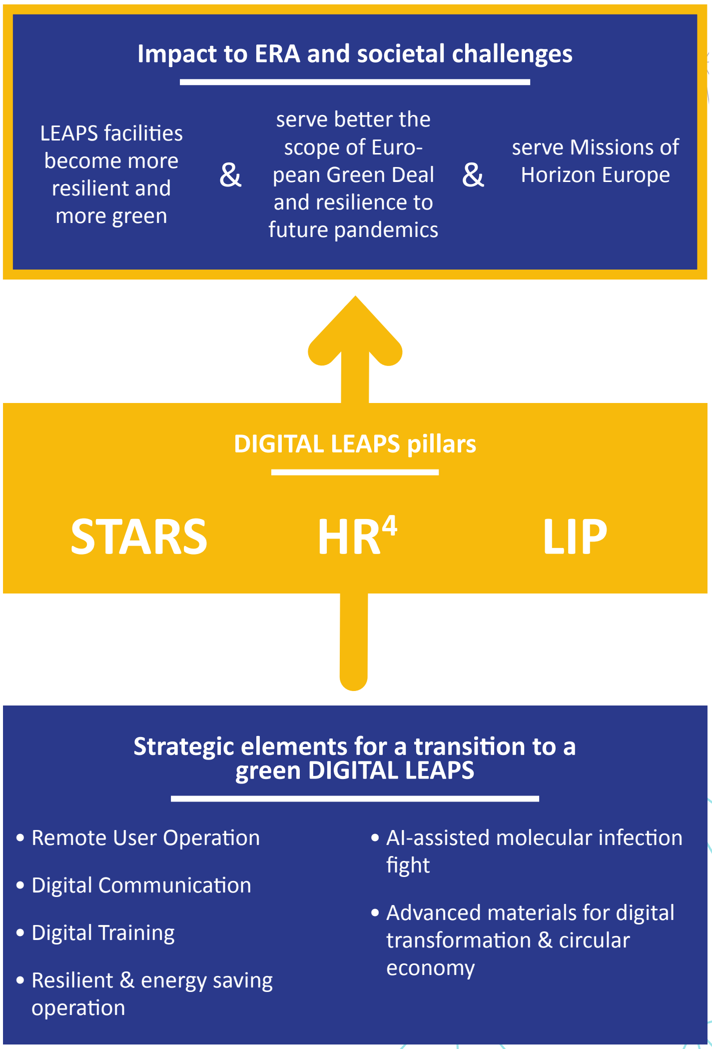


Fig. 4 The DIGITAL LEAPS (DL) project

Example TANGO[14] collaboration Experimental stations, beamlines and accelerator at synchrotron and FEL radiation sources require sophisticated, real-time capable control software for their operation. This software requires handling complex control issues and measurement procedures with many input parameters as well as monitoring hundreds of thousands of control points. In view of the quest for higher automation and more remote control and access of experiments at large scale facilities as well as the increasing complexity e.g. of real-time in situ and operando experiments the importance and impact of control software continues to grow as well as the effort in writing those codes. The international TANGO collaboration with 9 main and about 40 further partners from large scale facility operators, academia and industry is addressing this challenge in a synergistic manner through joint developments and is of very high strategic importance for the efficient use of these facilities by a broad user community. TANGO has been adopted by other communities like laser e.g. ELI, and astronomy e.g. SKA + LOFAR 2.0. Over 20 companies are involved. TANGO is Open Source software free for all to use.

4.2 Towards open science

Large-scale research infrastructures produce massive amounts of scientific data daily. Today, the amount of data doubles every year, and the increase of volume is expected to continue. This poses storage and (re)usability challenges, which are best addressed by the 'FAIR' paradigm: Findable, Accessible, Interoperable, and Re-usable.

Recognising the importance of fostering open science and open innovation, the EC supported the idea of a European Open Science Cloud (EOSC) that took shape in 2015. In the initial phase of implementation, the EC invested around €250 million to prototype components of the EOSC through calls for projects under Horizon 2020.

Two projects, PaNOSC[12] and ExPaNDS[13], were funded to develop the EOSC for the photon and neutron community. The outcomes of these two projects have been the publication of open data, the development of federated open data catalogues, EOSC-ready community Authentication and Authorization Infrastructure (AAI), and services for remote data analysis, simulation and an e-learning platform. These outcomes are necessary for the adoption of FAIR data practices and to fully exploit data coming out of the LEAPS facilities.

LEAPS has put large efforts into realizing the idea of open science beyond the EOSC clusters PaNOSC/ExPaNDS. by supporting the FAIR principles of data produced at their facilities also in nationally funded initiatives. Many LEAPS members became members of the EOSC Association. Thereby, LEAPS strongly supports the principles of the EOSC improving the situation of researchers and deepening the new European Research Area. The availability of metadata on publicly available sets is one of the key aspects and one of the objectives of the DIGITAL LEAPS STARS project.

Horizon Europe should allow efforts/ collaborations initiated in the framework of H2020 EOSC cluster projects to be pursued, consolidated, and developed.

To capitalize on these efforts towards open science, investment in sustaining and strengthening open science activities are envisaged to develop a photon and neutron PaN Open Data Commons as an essential component of EOSC for showcasing and accessing data.

The PaN Open Data Commons will enable new user communities to access and exploit the unique data being produced at the LEAPS facilities to do new science e.g. the Human Organ Atlas is revolutionizing digital histology and medical research with high resolution 3D volumes of complete human organs.

[12] The Photon and Neutron Open Science Cloud (PaNOSC) - Panosc
[13] expands.eu
[14] Home - TANGO Controls (tango-controls.org)
[15] https://human-organ-atlas.esrf.eu

5
TRANSVERSAL PRIORITY ACTION ITEMS

Today, the European users of synchrotrons and FELs are an open and extremely innovative community, still growing due in part to the increasing number of users from Eastern European countries. LEAPS facilities are meetings hubs of international, interdisciplinary and intermixed scientific groups and highly interlinked with neighbouring research infrastructures.

5.1 Training

LEAPS members are a perfect mix of research infrastructures and user facilities. Highly motivated and experienced staff develop and operate instruments, pushing the technology limits beyond state-of-the-art to conduct experiments at the forefront of science, blending technical knowledge with an awareness of the scientific challenges nurtured by the extensive user community, with whom the interaction is a continuous enrichment process in both directions. The multiple ERC grants addressing the evolution of methods at LEAPS RIs or accessing them for their unique analytical capabilities are successful examples of the fertile environment for scientific job developments.

Specific education and training as well as dedicated career development programmes will sustain and develop such staff. LEAPS proposes a **multidisciplinary European curriculum** targeting scientists, technicians and engineers as well as future managers. It will include mobility and exchange programmes, and mentoring of the early career staff. It will be balanced in terms of race and gender.

LEAPS RIs are key hosts of training programmes for users and for young staff including scientists and technicians.

The **European Synchrotron and Free Electron Laser User Organisation** (ESUO)[16], founded in 2010, represents the interests of 25,000+ users of SR and FEL facilities in Europe through delegates from 30 nations nominated by national/facility user organisations or equivalent and via a 8-member Executive Board. ESUO's vision is to support a thriving European synchrotron and FEL user community with equal opportunities of access and participation for all scientists based solely on the scientific merit of their ideas. ESUO's mission envisages achieving continued unencumbered access to SR and FEL research infrastructures, ideally eliminating geographic or financial barriers in user participation, and with as simple an access model as practicable[17]. In addition, ESUO seeks to improve gender balance among users, foster contacts and share knowledge with users from widening countries, co-develop actions for advanced techniques and beamlines with LEAPS, and also to collaborate with user organisations of other ARIE analytical facilities. ESUO is LEAPS Strategic Partner since 2021.

Strenthening the bridges between the academic and the industrial world is needed to foster innovation. Development of careers and sharing years of staging in both realities will help in creating a common language, and in providing public researchers and engineers a business vision of applied research as well as an innovation vision to industrial staff.

5.2 LEAPS-IDEA, a toolbox of best practices at LEAPS facilities[18]

LEAPS is committed to strengthening diversity and is acutely aware that it owes its success to the talents, ideas, cooperation, collective and complementary collaboration of its staff. The ingredients in this success are respect and fairness, appreciation and openness. LEAPS responsibility is, ensuring equity and achieving an inclusive environment, free from discrimination at all levels.

The prerequisite to scientific and societal prosperity is the creation of an atmosphere of acceptance and trust, embracing all differences stemming from personal ways of life or personal living situations, ethnic origin, gender, sexual orientation, ideologies, biographies, religion, beliefs, disability, age, appearance, and many other aspects. In an increasingly globalized and interdependent world, cohesion matters, diversity helps and impartiality is indispensable.

LEAPS recognizes that scientific communities, as all communities, are built by individuals informed by their own experience, circumstances, geographical origin, unconscious biases and greater society.

In order to achieve the goals of inclusion, diversity, equity and anti-discrimination, it is our commitment to provide a range of specific tools, tailored to each of the LEAPS facilities, making them the ideal location for large international, interdisciplinary and intermixed teams to thrive and achieve their highest potential.

- Trans-national Access
- Enable access to countries without facilities
- Young researcher bonus/mentor

LEAPS is already an ideal location to achieve the goals of inclusion, diversity, equity and anti-discrimination.

16 ESUO website: http://www.esuo.eu/

17 "Towards Even Brighter European Photon Science" https://www.esuo.eu/about-esuo/towards-even-brighter-european-photon-science-the-esuo-manifesto-for-a-truly-european-photon-science-community/

18 LEAPS-IDEA-September-2021.pdf (leaps-initiative.eu)

5.3 Synergies with neighbouring research infrastructures

LEAPS offers a rich diversity of analytical tools based on the synchrotron and FEL radiation capacity of interacting with matter. The complexity of understanding the properties of matter is also addressed by other analytical instruments, which make use of different and complementary probing instruments and methods.

In 2020 LEAPS triggered the creation of the network of Analytical Research Infrastructures in Europe (**ARIE**) - all together providing unique windows into the workings of the world around us. ARIE includes the powerful photon sources, such as synchrotrons, FELs and laser systems; sources of protons for beam-therapy, of neutrons and of ions; and facilities dedicated to advanced electron-microscopy and high-magnetic fields, altogether comprising more than one hundred facilities. This networking of RIs, unique in the world, enables LEAPS together with its neighbouring RIs to react quickly and effectively to address societal challenges as a strong stakeholder within the European Research Area.

Position papers[19], on-going projects as a result of answering to EC calls, information to the wide user community, fruitful exchanges of information cross-communities, have been the initial focus of networking and will further develop in the future.

ARIE[20]: centres of scientific and technological excellence, delivering services, data and know-how to a growing and diverse user community of more than 40,000 researchers in academia and industry, across a range of domains, e.g. physical sciences, energy, engineering, environment and earth sciences, as well as medicine, health, food and cultural heritage. The insights into materials and living matter made possible by their collective tools underpin the advanced research necessary for the success of the Horizon Europe Missions. The ARIEs provide free access to the scientific user community based upon scientific excellence and open data.

iNEXT-Discovery enables access to structural biology research infrastructures for all European researchers, and especially also for non-experts in structural biology, contributing to the sectors of health (e.g. drug discovery, target validation), biotechnology (e.g. new enzymes), biomaterials, and food science. It brings together a diversity of large research facilities and other groups in a single consortium. Funded by the European Commission Horizon-2020 framework programme from February 2020 for a period of four years, iNEXT-Discovery is built on three pillars:

- Allowing Trans-national access for external researchers, following rapid peer-review on scientific excellence and translational research potential.
- Performing **networking and training** activities, such as practical courses and workshops, to enlarge and strengthen the structural biology community.
- Undertaking **joint research** activities, to increase the quality and quantity of the access offered by our facilities.

NFFA-EUROPE PILOT (NEP) expands and consolidates the operation of an Interoperable Distributed Research Infrastructure for Nanoscience (IDRIN), supporting research on materials and functional systems at the nanoscale and at the microscale. NEP provides a unique overarching offer of experimental and theoretical facilities to suit user needs ranging from materials synthesis, growth, nanofabrication to nano-characterization, microscopy and spectroscopies also with fine analysis methods at LEAPS, LENS, Laserlab and eDREAM facilities, and to numerical simulation.

An overarching metadata and data management tool (Metastore) will realize the interoperability of the NEP results and a unique open access archive of FAIR nanoscience data to merge with the EOSC. The multi-technique character of the NEP user proposals leads to the advanced reproducibility of results, research goals and effectiveness in multi-disciplinary research for curiosity driven, mission-oriented and application-oriented projects by academic or industrial users. The construction of the IDRIN will address the issues for Long Term Sustainability of the NEP infrastructure services.

Instruct-ERIC[21] is a pan-European distributed research infrastructure making high-end technologies and methods in structural biology available to users. Their aim is to promote innovation in biomedical science and operates on a not for profit basis within the scope of the ERIC Regulation. Instruct-ERIC provides open access to cutting edge structural biology, specifically supporting research that uses integrated approaches and technologies. It operates with the following principles: a) scientific excellence is our priority in the services we provide and the research we support; b) transparency, equality and legality is the cornerstone of our operational model. Instruct-ERIC provides also access to synchrotrons being part of LEAPS.

[19] https://leaps-initiative.eu/wp-content/uploads/2021/10/DIGITAL-LEAPS-August-2021.pdf
[20] Home - ARIE-EU
[21] instruct-eric.eu

6

CONCLUDING REMARKS

The European Strategy ESAPS 2022 charts a route into the future that features environmentally friendly technologies and research strategies to support solving societal challenges while making a critical contribution to keep Europe at the international forefront of research and development.

The **European Strategy ESAPS 2022**

- supports high quality scientific research in Europe
- contributes to develop the skills of the next generation of scientists and engineers in Europe
- devises particle accelerators and associated technologies of tomorrow for a wide range of use in manufacturing and service industries in health, materials design, energy and security
- supports European industry in new product development and market and by accelerating product design and development,

ESAPS 2022 was adopted at the General Assembly Meeting of LEAPS on March 11, 2022.

7 ANNEX

7.1 Acronyms

AI	Artificial Intelligence
AMO	Atomic and molecular science
ARIE	Analytical Research Infrastructures in Europe
DL	Digital LEAPS
EBS	Extremely Brilliant Source
EOSC	European Open Science Cloud
ESAPS	European Strategy for Accelerator-based Photon Science
ESUO	European Synchrotron and FEL User Organization
FAIR	Findable, Accessible, Interoperable, and Re-usable
FEL	Free Electron Laser
LEAPS	League of European Accelerator-based Photon Sources
LOFAR	Low Frequency Array
R&D	Research and Development
RI	Research Infrastructure
SKA	Square Kilometer Array
SR	Storage Ring
TNA	Trans-national Access

7.2 LEAPS Numbers and Facts

The advancement of Science on the discovery and characterisation of advanced materials, biomaterials and living matter is linked to the essential role played by Synchrotron Radiation (SR) and Free Electron Laser (FEL) user facilities. Europe has achieved global leadership in this field. European SR and FEL facilities serve a very broad scientific community, with more than 35,000 researchers in Europe and beyond, and attract some of the brightest minds worldwide. They serve many countries, facilitating multinational collaborations, and support a spectrum of disciplines that encompass fundamental and applied sciences, and innovative industrial applications; they provide answers to key societal challenges in areas such as health, environment, energy and communication; they educate and form the next generation of scientists, engineers and facility managers and administrators, and contribute strongly to the competitiveness of European science and industry, thus generating jobs and wealth.

The delegates of the SR and FEL user facilities in the EU and associated countries have decided to establish a strategic Consortium – the **League of European Accelerator-based Photon Sources (LEAPS)** – the primary goal of which is to actively and constructively ensure and promote the quality and impact of the fundamental, applied and industrial research carried out at their respective facilities. The LEAPS Consortium deploys its substantial collective knowledge, experience and expertise in SR and FEL science and technology, Research Infrastructure management, and service to scientific users and stakeholders to the greater benefit of European science and society. It further aims to play an integrating role for countries with less developed communities and infrastructure for research and innovation, in Europe and beyond.[22]

19 facilities **16** institutions **10** countries

>300 operating End-Stations **>5.000** publications / year

>1.000.000 h beam time / year **>15** spin off companies

>35.000 user / year from all EU and beyond researchers from all research areas

[22] LEAPS declaration (latest version June 2021)

7.3 LEAPS Facilities

STORAGE RINGS

FACILITY	LINK
ESRF EBS	www.esrf.fr
PETRA III	https://photon-science.desy.de/facilities/petra_iii/
PETRA IV	https://photon-science.desy.de/facilities/petra_iv_project/
ALBA	www.albasynchrotron.es/en/
ALBA II	www.cells.es/en/science-at-alba/alba-ii-upgrade
DIAMOND	www.diamond.ac.uk
DIAMOND-II	www.diamond.ac.uk/Diamond-II.html
MAX IV	www.maxiv.lu.se
MAX IV (up)	https://www.maxiv.lu.se/science/accelerator-physics/current-projects/max-iv-brightness-up-grade-project/
SOLEIL	www.synchrotron-soleil.fr
SOLEIL up	https://www.synchrotron-soleil.fr/en/spreading-scientific-knowledge-one-soleils-missions/get-information
SLS	www.psi.ch/en/sls
SLS 2.0	www.psi.ch/de/sls2-0
ELETTRA	www.elettra.eu
ELETTRA II	https://www.elettra.eu/lightsources/elettra/elettra-2-0.html
BESSY II	www.helmholtz-berlin.de/forschung/quellen/bessy
BESSY III	www.helmholtz-berlin.de/forschung/quellen/bessy3
SOLARIS	https://synchrotron.uj.edu.pl/en_GB/
ASTRID2	www.isa.au.dk/index.asp
MLS	https://www.ptb.de/ptb-sr

FREE ELECTRON LASER

FACILITY	LINK
European XFEL	https://www.xfel.eu/
SwissFEL	www.psi.ch/en/swissfel
MAX IV SXL	www.maxiv.lu.se/science/accelerator-physics/current-projects/the-soft-x-ray-laser-sxl-project
FERMI-1	www.elettra.trieste.it/lightsources/fermi
FERMI 2.0	www.elettra.trieste.it/images/Documents/FERMI Machine/Machine/CDR/FERMI2.0CDR.pdf
FLASH 1	https://photon-science.desy.de/facilities/flash/index_eng.html
FLASH 2	www.desy.de/e141261/e158573/e158650/e164235/index_eng.html
FLASH 2020+	www.desy.de/research/facilities__projects/flash2020/index_eng.html
EuSPARC	https://home.infn.it/en/european-projects
SPARC	http://www.lnf.infn.it/acceleratori/sparc/
CLIO	http://clio.lcp.u-psud.fr/
FELBE	www.hzdr.de/db/Cms?pNid=245&pLang=en
TELBE	www.hzdr.de/db/Cms?pNid=245&pLang=en
DALI	www.hzdr.de/db/Cms?pOid=64492&pNid=0&pLang=en
FELIX 1/2	www.ru.nl/felix/about-felix/about-felix/felix-laboratory/

Fig. 5 LEAPS and its partners

EDITORIAL BOARD

Images

Page 8: Molecular structure of the light receptor in the eye
Credit: Adobe Stock

Page 13: 3D Imaging of a human lung
Credit: ESRF

Strengthen Europe's leading role in science and innovation

https://leaps-initiative.eu

LEAPS League of European Accelerator-based Photon Sources