EUCALL

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Synergy and Innovation Potential of EUCALL

Lead Beneficiary: ELI

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Contents

1. Introduction

It is the goal of EUCALL to analyze the synergies and the combined innovation potential of the advanced laser light source research infrastructures and to make recommendations how to further develop and enhance both of these. This report summarizes the findings of this activity. Two major activities were performed: EUCALL members performed a detailed study of the current experimental capabilities of a wide range of light sources in Europe, including all EUCALL light sources, but also further selected ones. As second activity consisted of a series of interviews with EUCALL facility representatives to understand how these cooperate with industry. The collected information has been condensed and was presented for analysis to EUCALL's Synergy Board. The information about the EUCALL light sources and instruments was further provided to external experts in order to analyze the potential for more efficient use of the facilities and the possibilities for optimization of user research opportunities.

To analyze the combined research potential of the facilities involved in EUCALL, a collection of each facility's current (or planned) experimental capabilities for the ultraviolet and x-ray photon energy ranges has been performed. Characteristics of 121 beamlines and instruments at selected European free-electron laser (FEL), synchrotron radiation and optical laser research infrastructures were collected and compiled into a comprehensive spreadsheet. This collection presents the basis for the analysis of the combined research potential presented in Section 2. During the course of the project it was recommended, by EUCALL's Scientific Advisory Committee (SAC), external experts, and also by EUCALL members, to develop this spreadsheet into a searchable database, which should be provided to users and RI operators to better oversee the various installations and to be able to locate suitable beamlines/instruments for their given experimental requirements. In order to render this effort sustainable beyond the duration of the EUCALL project it was decided to integrate this information into an existing and similar database for synchrotron and FEL facilities operated by Elettra at the website www.wayforlight.eu.

The analysis of the potential for more efficient use of the EUCALL facilities, but also for future optimization of the user research opportunities is based to a large extent on the involvement of a group of expert users of the surveyed light sources. The experts were invited, using the spreadsheet, to provide feedback on missing elements and potential synergies of the combination of facilities and research opportunities. This feedback by the expert users, combined with a series of interviews concerning subscription rates of the various facilities, has then been used to summarize the potential for more efficient use and future optimized research opportunities in Section 3.

In order to respond to the task to identify the combined innovation potential of the EUCALL facilities an extensive survey has been performed among the technology transfer offices of light source RIs regarding their support of innovation and cooperation with industry. The results have been analyzed and patterns and best practices have been identified and are presented in Section 4.

EUCALL has organised the experience exchange workshops “User Access at Advanced Laser Light Sources” and “Innovation Potential of Advanced Laser Light Sources”. At these meetings, staff of each EUCALL partner gathered to discuss best practices and to develop recommendations for future synergies and long term collaborations. Finally, in Section 5 we summarize the overall findings of this report and with respect to the goal of EUCALL to analyze the synergies and the combined innovation potential of the advanced laser light source research infrastructures.

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2. Analysis of the combined research potential of the EUCALL facilities

The goal of this activity is to establish a comprehensive overview of the various light sources, their parameters and instrumentation, but also complementary installations, such as for sample preparation and analysis. This set of parameters and instrumentation defines the background on which research opportunities exist and can develop. We describe first the collection of data from the various facilities, before introducing a first analysis of the completeness of the data. We also present a first set of findings. In the final part of this section we describe the effort to make the data available to users and facility operators to become a sustainable tool supporting a more efficient use of the EUCALL facilities.

2.1 Compilation of spreadsheet

The characteristics of interest for instruments/beamlines at free-electron laser (FEL), optical laser and synchrotron radiation facilities were defined by EUCALL WP3 members and the EUCALL SAC. The data collection focused on user-access beamlines of UV and x-ray radiation which either have laser characteristics, or combine optical lasers with x-rays for scientific analysis. The beamlines/instruments studied included all 23 FEL installations for this wavelength range, 13 optical laser beamlines (in the UV and x-ray energy range) as part of ELI and a selection of 30 optical laser beamlines for the UV to x-ray range of Laserlab-Europe installations, and also 55 selected synchrotron beamlines with properties such as:

- Capabilities for pump-probe experiments with optical lasers;
- Instrumentation for dynamic compression with optical lasers;
- UV or x-ray photon beams with a high degree of coherence;
- UV or x-ray photon beams with femtosecond pulse duration.

The data collection was performed in several categories, such as properties of UV/x-ray photons generated, experimental techniques, properties of associated external optical lasers and supporting infrastructure. By supporting infrastructure, this could mean for example experimental environment and data acquisition support. This collection was performed for all relevant EUCALL partner light sources, as well as for some external light sources with instrumentation equivalent to EUCALL facilities, such as exists at Diamond Light Source, BESSY II or SOLEIL. The data were mostly collected from the facilities websites. For some facilities/instruments, input from the beamline scientists was asked in order to complement the website data.

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The collected information has been compiled on a large spreadsheet. In total, 121 beamlines/instruments at 17 Advanced Laser Light Source Research Infrastructures (ALL-RIs) have been listed, and for each of these beamlines/instruments it was attempted to fill entries for the 22 different characteristics, resulting in almost 2700 elements in the spreadsheet. The facilities within the Laserlab-Europe consortium are presented as a single RI.

Finally, the completed spreadsheet was made available to the Synergy Board, the SAC and later also to external experts for further analysis and as a basis for recommendations about a more efficient facility use and an optimization of research opportunities (see Section 3).

2.2 First analysis of collected data

This data collection was largely dependent on the data present on the RI websites. In cases where the characteristics of UV and x-ray beamlines available on the websites were not complete, or obviously outdated, it was attempted to collect complementary information by the respective instrument scientists. Nonetheless, in some cases not all characteristics could be filled. We would like to stress that we believe the findings reported in this document are valid irrespective of this missing information. However, we note that the presentation of such important data on the RI websites is most useful when it is complete and kept up to date. Users otherwise may experience difficulties in selecting the appropriate instrumentation for their experiments, which can render experiment preparation inefficient and experiments unsuccessful.

Another finding is that there exists a marked difference between the accelerator-based facilities and the optical laser-based facilities. While the accelerator-based facilities often provide a high degree of differentiation of instrumentation for specific applications, the optical laser-based facilities put a much higher emphasis on the optical lasers which drive the secondary UV/x-ray sources. This difference might be related to the difference of the respective user communities of the two types of light sources. Similarly, but different in origin, the description of light source properties and adjacent additional light sources, e.g. optical lasers for pump-probe type experiments, is more detailed and specific for that type of source, the facility is belonging to, meaning either accelerator-based or optical laser-based UV/x-ray source.

A specific aspect of the compilation of a spreadsheet was the possibility to identify and analyse duplications of capabilities among the European RIs, which might be considered as an inefficient use of resources. However, we stress here that the spreadsheet alone is not sufficient to allow such a judgement. Below we give two examples where the spreadsheet indicates several installations with an “at first glance” very similar capability to produce science. It turns out that a high demand of these facilities and a high degree of differentiation concerning very specific aspects, in particular in the area of the user and sample domain, can lead to a situation where multiplying certain capabilities enables the best science, provides researchers access to facilities without too much delay, and therefore actually generates a more efficient use of resources.

As a first example, the spreadsheet has been analyzed to determine how many instruments can be used for “x-ray diffraction” using “hard x-rays” (defined in the spreadsheet as photon energy 6 – 25 keV). It was found that 29 instruments/beamlines are available here. However, this relative large number shrinks if one includes the type of light source with its different characteristics: Five instruments are located at FELs, two at optical laser sources and 22 at synchrotron facilities. Another differentiation is in the area of specific sample environments. Out of the 29 installations only 20 provide cryogenic or high (or both) temperature environments, again spread over the different types of light sources.

A second example searching the data collection for “x-ray absorption spectroscopy” in the water window energy range (280 – 530 eV) results in 35 instruments/beamlines (9 FEL, 13 at optical lasers, 13 synchrotron instruments). However, the spreadsheet detail limits the search parameters to “spectroscopy” which includes a number of different spectroscopy techniques, such as x-ray absorption, photoelectron emission, Raman spectroscopy, and others. Also “soft x-rays” (defined in the spreadsheet as 200 – 2000 eV) represents a fairly broad range enabling specific scientific use at different photon energies. The large number of installations for “spectroscopy with soft x-rays” therefore partly originates in a limitation of the spreadsheet, as exact photon energy ranges cannot be identified, and the different types of spectroscopy experiments cannot be distinguished.

These apparent limitations of the spreadsheet are needed on the other hand to create some level of categorization required to make its use feasible. If every detail would lead to a new characteristics or category the spreadsheet would become a lot more complex in establishing, maintaining and reading. However, it will be attempted to overcome some of these limitations with an expansion of the spreadsheet data as part of its integration with the Wayforlight database (see Section 2.3). In addition to the before analysis it was found that the multiple provided experimental techniques are in high demand by users, and the User Offices of the EUCALL RIs report oversubscription factors of 2-3 at their instruments (see Section 3.2) demonstrating the high need of multiple installations.

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2.3 Building a database included in www.wayforlight.eu

At the EUCALL Scientific Advisory Committee (SAC) meeting 2016, the SAC recommended that the spreadsheet data should be developed into a tool that is made available to the user community, facilitating the process of finding the right facility for their specific requirements for experiments and research, and to facility operators, providing them an overview of installations and their capabilities in Europe. The expert users (see Section 3) later similarly requested that the data in the spreadsheet be made publicly available and that functionality is incorporated allowing the user to reorganize the data, for example according to experimental technique or photon energy. The SAC also suggested that the data be provided in a searchable database format, rather than in the form of a table. In this context the question of long-term sustainability of such a database needed to be addressed. As pointed out above, it needs to be ensured that the information underlying the database is kept up to date, and that future updates of the database are possible. This aspect of sustainability is particular important since the EUCALL project ends in September 2018.

To address these requests, WP3 members engaged with the operators of the Wayforlight database, developed under the CALIPSO FP7 project and maintained at Elettra. The website www.wayforlight.eu contains a very useful database which offers a portal to and information about many of the European FEL and SR facilities. This database was created under the CALIPSO (FP7) project and is kept up to date by staff of the participating RIs entering data manually. Wayforlight is a publicly available database allowing users to find the correct instrumentation for their experimental needs. For these searches Wayforlight uses specific characteristics like the type of light source and the technique requested, and asks the user to define desired characteristics like photon energy range, beam spot size on sample and sample size by means of 'sliders'. Following discussions with Elettra, it was agreed to incorporate the EUCALL spreadsheet data into the Wayforlight database. In particular, this meant to extend the www.wayforlight.eu website to include optical laser driven light source RIs, such as the ELI and the Laserlab-Europe UV and x-ray facilities. EUCALL's extension of Wayforlight also enables better visibility of optical lasers present at the instruments, and includes a new functionality in which the data entered into the Wayforlight database can automatically be incorporated and displayed on the RI's own website. EUCALL is currently preparing a prototype for the extended Wayforlight database which contains the instrumentation collected in the WP3 spreadsheet (121 instruments at 17 RIs), to be completed and online before the end of the EUCALL project. The other RIs with instrumentation already presented on the Wayforlight database, but not included in the EUCALL prototype will be encouraged to integrate their data into the new database.

3. Efficient use of RIs and optimization of user research opportunities

In this section we report two major activities. Firstly, we have used the data spreadsheet described in Section 2 to inquire feedback from expert users about the present situation of advanced laser light sources in Europe, also comparing to the situation elsewhere in the world. This feedback is summarized in various categories in Section 3.1 and individual feedback is listed in the Appendix. Secondly, we summarize in Section 3.2 the discussions and feedback from a EUCALL experience exchange workshop of User Offices to make conclusions about the efficient use of the facilities.

3.1 Potential for improvements of EUCALL facilities

The spreadsheet introduced in Section 2 summarizes the present status of EUCALL facilities and several others. It is the aim of the following described activity to analyze this status with respect to its shortcomings, potential for more efficient use and also possible optimizations of user research opportunities. In order to perform such an analysis the Synergy Board decided to involve expert users of the various facilities. For this the Synergy Board identified experts from various scientific fields associated to each of the instruments included in the spreadsheet. The experts should be worldwide leaders in their respective fields and users of existing and planned UV and x-ray beamlines/instruments, meaning that they both have a good overview of scientific demands in a range of applications exceeding their own research and are knowledgeable about developments at facilities outside Europe. It was further decided that the experts should not be themselves responsible for any instruments or source development at light source RIs in order to provide an as much as possible unbiased user perspective. 31 experts were identified out of which 17 provided feedback to our request.

The experts were provided with the spreadsheet and a questionnaire (designed by the Synergy Board and included in Annex 1). The questionnaire included questions about which facilities the expert uses, availability of RIs in Europe, conditions to use different types of RIs, observed issues and missing elements, potential synergies and recommendations about the European landscape of advanced laser light sources. In addition, the experts had to identify themselves as member of a certain scientific community, thereby allowing understanding different requirements by different scientific communities. The responses in detail are included in Annex 2.

In addition to the feedback summarized below under a few specific headings, many experts stated that the data collected in the spreadsheet are very useful to them and recommended the data to be made available to all the users of European light sources. In this context, the

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expert users indicated the following two criteria to be most important for users when selecting a beamline/instrument at an RI for their proposal and experiment:

- The availability of a proven technology or parameter range, necessary to perform a specific type of experiments.
- The general quality of the instrumentation at the respective RI, composed by the available equipment to prepare and conduct the experiment, an efficient operation of the beamline/instrument ("Push button operation and reliability of the light source"), the overall feeling that the experiment will be more likely to succeed thanks to the environment provided at the respective RI, which is not restricted to, but certainly involves the quality of user support. In particular, the quality requirements for user access are considered as critical in the decision process.

New research opportunities

The answers in this category addressed primarily the possibilities opening by adding to the instrumentation at specific beamlines, the advantages of increasing the light source parameter range, and of new source developments.

The advantages for additional instrumentation were highlighted in particular for FEL and optical laser based beamlines where a higher differentiation with specialized experimental end-stations, incorporating features such as low temperature, external fields, and *in-situ* sample preparation today commonly found at synchrotron facilities, would support user needs significantly. Another extension opening new opportunities was identified by the incorporation of complementary characterization techniques, for instance optical spectroscopies such as Raman and infrared, including multidimensional measurements. Users from all scientific areas pointed to the benefits of a higher availability of spectroscopic methods, covering the full spectrum from infrared to hard x-rays, to determine vibrational, electronic and atomic structure after optical excitation.

An extension opening new and complementary investigations could make direct use of the electron beams generated at many of the EUCALL facilities. In particular, the use in ultrafast electron diffraction experiments would enhance the material analysis capabilities of light sources. Furthermore, the availability of electron beams synchronized with optical laser beams open the possibility of pioneering experiments using photons as a pump and electrons as a probe or vice-versa. A concept for how to apply the accelerated relativistic electron beams at light sources into such ultrafast electron diffraction setups could be jointly developed between RIs.

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The application field of extreme conditions was strongly present in the feedback by the expert group. This community already uses both accelerator and optical laser light sources and therefore is prominently present in the EUCALL project and the field of advanced laser light sources. This community considered that Europe is at the forefront of research, namely with the upcoming European XFEL's High Energy Density (HED) instrument and the ESRF High Power Laser Facility (ESRF-HPLF) upgrade, but it also notes the absence in Europe of a synchrotron-based x-ray diffraction and imaging capability in connection with a high-energy drive laser. The community further notes a worldwide lack of an facility combining an optical laser of the scale of those at the National Ignition Facility (NIF, USA) or the CEA's Megajoule Laser (LMJ, France), with an x-ray FEL, potentially opening the ability to obtain the most extreme conditions through probing with a high quality short-pulse x-ray beam. Such a facility would undoubtedly lead to new research opportunities. An emerging recommendation for the future is that future high average power laser facilities could be sited in the close vicinity of x-ray FEL facilities; or a future x-ray FEL could be sited beside a large laser facility.

User groups further indicated that they would benefit from laser driven, compact x-ray sources which they could set up in their home laboratories, to prepare for high-end experiments at RIs. The capability of users to prepare extensively for RI beamtime in this manner could significantly improve the effectiveness of beamtime use. It was considered if light source RIs could offer support and expertise to user groups in developing such compact x-ray sources with comparable characteristics.

In the area of light source parameters, in particular the provision of high repetition rates for the time-resolved investigation of dynamic processes and for studying extremely dilute samples was highlighted. It was emphasized that synchrotron sources achieve high brilliance combined with high stability and small foci and that the new FEL and optical laser sources need to reach a similar performance, in particular accuracy level. This requirement could define a direction for future development of advanced laser light sources. Another opportunity was identified in maintaining UV sources for important challenges in atomic, molecular and optical physics as well as in condensed matter physics.

Possible synergies between facilities and/or fields

Synergies between accelerator and laser-driven light sources are already observable in the application of different types of light sources for studying dynamics at different resolution using the complementary nature of High Harmonic Gain (HHG), FEL and synchrotron radiation. At least in the UV and soft x-ray range, light sources of each type are operational and allow the complementary and synergetic study of a system's dynamics at various timescales: the attosecond to femtosecond timescale at an HHG source, the femtosecond to

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nanosecond scale at an FEL, and longer timescales using synchrotron facilities. Using the different types of sources spectral and structural studies shall allow for a complete analysis of the system under investigation. The different sources, in addition to the different time-scales, differ in other parameters: HHG sources have high spectral stability and synchronization between optical pump and soft x-ray probe pulse, and provide high longitudinal coherence properties. FELs have larger photon flux, higher brightness and allow for non-linear interaction studies even in the soft to hard x-ray domain. Synchrotron facilities provide extreme stability and thereby enable to reach extremely high resolution in spectral studies. Potential extension of the photon energy range of HHG sources into the tender x-ray range and of the time resolution at FEL sources into the attosecond range will in the future further enhance this synergy.

The extreme conditions user community in Europe will greatly benefit from the synergy between HED instrument at European XFEL (short timescale) and ESRF-HPLF (longer timescales) for dynamic compression studies.

It was further emphasized that potential synergies can be particularly well exploited by individual user groups when complementary light sources are located in close proximity to one another, such that users can perform experiments using different light sources during the same measurement campaign. Currently the Saclay region in Paris, Lund in Sweden and the Harwell Science Campus in UK host both a synchrotron and an optical laser facility in close proximity. In Hamburg a combination of the PETRA-III synchrotron light source and the FLASH FEL at DESY, combined with the European XFEL allows covering a huge spectral range at synchrotron and FEL facilities. In addition, there are some optical laser driven light sources albeit not yet in user operation. Furthermore PSI hosts both a synchrotron and a FEL facility. While Europe has several synchrotron sources with nearby FEL sources, the unique capability of combining an x-ray FEL with synchrotron radiation and two high energy and high peak power lasers in a single experiment environment can only be found at SACLA/Spring-8 in Japan. Similar synergies of different types of sources are observed with the proximity of light sources to neutron sources – such as which exists at PSI, the ESRF/ILL campus, the MAX IV/ESS campus, and at the Harwell Campus in UK. The above described colocation of different sources creates synergies in operation and research which may be considered in the future when building new light sources in Europe.

Considering the identified limitation of established end-stations for users at FEL and optical laser sources, a possible synergy could be to establish the sharing of designs for such instrumentation between facilities, to encourage joint development and standardization of equipment. This could also contribute to more efficient use of the facilities by users, as they would find standardized end-stations and other equipment at different facilities. Such

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dissemination of knowledge and sharing of techniques have been successfully implemented in the networking activities of Laserlab-Europe. This also encourages joint staff training, as technicians and engineers are exchanged between RIs to learn how to operate the shared equipment.

The extreme conditions user community notes further that the development of new opportunities in extreme conditions research will depend on the availability of targets for user experiments and expect that the facilities will need to significantly support complex sample preparations. Sharing targetry fabrication capabilities at the European level appears to be a necessity and offers many opportunities for developing synergies between facilities and expert user groups. Preliminary discussions started on the establishment of a European Target Network. This topic has also been identified as one of EUCALL's Joint Foresight Topics (Deliverable 3.4).

Landscape of light source RIs in Europe

The expert users reported satisfaction with the instruments and beamlines available at the different RIs in Europe, and confirmed that the facilities and instruments included in the spreadsheet are indeed the key advanced laser light source research infrastructure in Europe for to UV to x-ray regime. Outside Europe, the most used facilities by the expert users are the LCLS (USA) and SPring8/SACLA (Japan), reflecting the situation without an operational x-ray FEL in Europe at the time of the survey. The recent start-up of both European XFEL and SwissFEL, directly after EUCALL's data collection, is expected to satisfy this need.

3.2 Optimum use of the infrastructures

The conditions and parameters qualifying an optimum use of the facilities were discussed between the facility User Office staff during the EUCALL Workshop: "User Access at Advanced Laser Light Sources" during 21-22 September 2017 at ELI-Beamlines. At this experience exchange workshop for 21 participants (staff of EUCALL facilities and some external facilities), the operators of each user facility exchanged information about their standard practices. Aside from the presentations at the workshop on topics including "Calls for Proposals", "User Portal", "Safety Training of Users, and Safety Staff", "Publication Database" and "Joint Access Policies", open discussions were held to address the limitations restricting the optimum use of the infrastructures and the optimum response to a variety of user demands.

Oversubscription

The oversubscription rate is the ratio of the number of proposals submitted for a given instrument to the number of proposals which can be awarded beamtime. The participating

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RIs generally report an oversubscription rate of 2-3 at their instruments, while some instruments in particularly high demand (for example FEL beamlines) have an oversubscription rate as high as 3-6. A high degree of oversubscription is considered by the RI operators to be a positive sign, as it reflects the high relevance of their facility and demonstrates a need for further funding and extension of facility capabilities. However, it also realized that a too high oversubscription demotivates users from applying for beamtime and thereby leads to a narrowing of the user community. This also provides a motivation to enhance the number of beamlines/instruments in areas of particular high user demand.

A proposed concept to redirect unsuccessful proposals to a different facility is considered by the User Office experts to be both unrealistic and not advisable. All facilities are similarly oversubscribed, and due to as the generally applied excellence-based selection method it would be the least successful project to be moved, at the same time the least interesting from the scientific point of view for the receiving facility. Some users apply in parallel to several facilities, in order to maximize their chances of success. These proposals are already reviewed by several facilities and do not qualify for such transfers. It is noted that there are some user groups which regularly succeed with their proposals and therefore receive significant amounts of beamtime, while other groups receive much less. But this result reflects the scientific excellence of those groups and should not be discouraged.

Limitations restricting the optimum use of the RIs

A key point which arose from the final discussion was the need for a balance, at each beamline, between high-risk experiments (more interesting and challenging, but possibly not resulting in publications) and "standard" experiments (with a high chance of publication). This balance allows that ground-breaking research is undertaken at each beamline, while ensuring a satisfactory number of publications generated each year. This goal is challenging to be implemented as it may interfere with the peer-review process. This process, set up to select experiment proposals according to their scientific quality, does in general not distinguish between "standard" and "high risk" experiment proposals. However, "standard" proposals have usually a better chance for publication and therefore a slight advantage in this selection process. In particular, if proposals from different scientific domains compete for the too little time available. New peer-review schemes, like currently established at ESRF and European XFEL, may ease this situation. Another possibility is that facility management utilizes is discretionary time to allocate high risk proposals. This scheme can, however, only be applied to few and exceptional experiment proposals.

Optimum response to user demands

Strong flexibility in planning is often required. For example, timing for a user's access must match the user's experimental constraints. For the case of protein crystallography, User

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Office experts reported that due to complicated nature of sample synthesis, users are constantly trying to produce protein crystals, and when they are successful they require rapid access to the light source infrastructure for measurements. In this case, some facilities offer access after a relatively short delay between proposal and actual beamtime due to the short lifetime of the samples.

How to best overcome those limitations on a larger scale across the two communities and optimization of the efficient use of an ensemble of complementary facilities

It is concluded that solutions to increase efficient use of the facilities will require further efforts beyond the EUCALL project. In particular, more in-depth discussions within the communities and more dedicated events to collect ideas and strategies are required. The communities will profit from more networking and shared events to have a better knowledge of each other and to work together on common solutions.

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4. Innovation potential of EUCALL

Representatives of Technology Transfer Offices and Industrial Liaison Offices from each of the EUCALL consortium's members, plus several external facilities, were interviewed about joint development of high-tech instrumentation with industry, protection and commercialization of intellectual property (IP), and commercial access policies for industrial use of RIs. The majority of facilities represented are located in Europe, with one each from USA and Japan included for benchmarking purposes.

This data collection showed that under-construction facilities, as ELI and European XFEL, had not yet fully defined their policies for Technology Transfer. To address the issue of innovation potentials, the EUCALL WP3 experience exchange workshop "Innovation Potential of Advanced Laser Light Sources" was held during 14-16 November 2017 in Sitges, Spain. At this occasion innovation policies were discussed between the facilities' Technology Transfer Offices. This gathering of Technology Transfer experts also enabled EUCALL to disseminate the preliminary results of its innovation surveys, and included panel discussions and working groups, to develop final recommendations regarding the best practices in technology transfer at photon science RIs as well as for the innovation potential of a combination of RIs.

4.1 Joint development of technology

Large RIs are important technology drivers through their need for state-of-the-art equipment, technologies, and methodologies, and through the limited life cycles and frequent upgrades of their equipment. In many cases, components of beamline infrastructure at modern facilities require a technical level that is not yet available from commercial suppliers or at other RIs, for example optical systems (mirrors, lenses) that can create the beam-focusing required, while withstanding the ultrahigh radiation intensities generated by FELs or optical laser facilities.

To ensure realization of such demanding technologies, many RIs collaborate with industrial suppliers. The RI provides their requirements to the industrial supplier, and the supplier develops the new technology. In some cases, the RI provides further support in this development. Finally, the supplier is able to sell their newly developed product to other consumers.

In many cases, detailed information of the collaboration between the RIs and the industrial partner (company names, exact description of the technology, and precise financial terms of the agreement) were not disclosed due to confidentiality restrictions.

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Models of Joint Development

It was possible to identify five different models describing ALL-RIs' joint development of technology with industry. The differentiating factor between them is the role of each partner in the joint development, with a focus on the ownership of the intellectual property and the development of know-how and engineering. In the following we define a "technique" as all the know-how or IP involved in a new idea or innovation, and we define "technology" and "engineering" as the work of realizing a prototype based on the technique.

1. **The RI provides the IP, the company provides the engineering.** In this model the RI has developed a new technique and has protected the intellectual property. The support of an external partner, a private company, is necessary as the prototyping, implementation and debugging of the technology derived from the RI's technique require methods and resources unavailable to (or difficult to obtain by) the RI. The RIs then licenses the technique to the company that will develop the technology, and the consequent royalty fees to the RI can be a direct measure of the usefulness of the technique in real-life applications. An example is PSI, which jointly developed a component of their on-site proton therapy center with an industrial supplier. The supplier now owns the license to this new technology, and can sell it commercially to other proton therapy centers, while PSI receives royalties from these sales.

2. **The RI proposes an evolution of a commercial product implemented at the facility.** In this model, while using a commercial product, RI staff identify a way to enhance the performances for a specific (scientific) application. This activity generates know-how or intellectual property. The ownership of the technique can be shared by the RI and the company or sustained only by the RI. Typically, the company then proposes the evolution of the product as an option or as a standard, depending on the usefulness of the technology, and rewards the RI with royalty fees. An example is at HZDR, which co-developed a few technologies with a laser supplier. This collaboration started with a purchase order that initiated the contact between the two groups, and now HZDR participates in the development of future products of the company and also receives royalties. In a further example, European XFEL staff modified the design of an instrument that was being built for them by an industrial supplier. The supplier then upgraded this instrument free of charge based on the designs of European XFEL and provided the improved instrument to European XFEL.

3. **The RI owns the IP and performs the engineering, the company manufactures the product.** In this model the RI could reach the market with the new technology independently from any form of partnership. RIs do not often select this option, as the service support and warranty expected by the customers from a manufacturer

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are incompatible with the operational model of a RI. Usually, the industrial partner duplicates an existing prototype to sell it and to service it. This approach to the collaboration can be regulated by royalty fees paid by the company back to the RI, but usually the deep involvement of the RI staff to transfer the technology to the company pushes the RI to consider the economical reward of establishing a joint venture with the industrial partner. This model could be of use to ESRF and ELI-Beamlines in the future to bring their own technologies to the market, as they report in the interviews that all their developments are done on site by their own staff.

4. **The RI proposes an idea, the company develops the technique and the technology.** In this model, the RI typically expresses an advanced requirement. If the potential market justifies it, a company can decide to develop the technique and the technology to realize the product. Due to the reduced involvement in the conception and realization of the innovation, the RI is typically rewarded with a free or discounted prototype. The RI usually acts as a beta-tester before the final version of the product reaches the market. In an example, a contract from European XFEL allowed a supplier to significantly expand its own expertise and capabilities, to produce advanced vacuum systems that can be of value to other research facilities (not only for ALL-RIs).

5. **The RI and a company create a so-called "Joint Lab**". Their efforts are joined, with shared resources in terms of work forces, financial support and equipment. This scheme is likely the most appropriate to ensure developing a successful long-term strategy, producing state-of-the-art outcomes that will fit the market. Each year the steering committee defines the new objectives and resources, as well as the calls which the Joint Lab should answer. These R&D oriented calls are frequent on national or European basis, their success rates are usually much higher than that of pure academic calls and they can bring significant financial support to the RI and to the company. Creating a Joint Lab also allows the motivation and training of technicians in charge of the routine exploitation of the RI, giving them the opportunity to use and develop world-class equipment. An example of a Joint Lab, formed with an optical laser RI, is the IMPULSE Joint Lab between Amplitude Technology and the Laserlab-Europe LIDYL laboratory of CEA.

Japan and USA

The synchrotron sources studied outside of Europe, NSLS-II (USA) and SPring-8 (Japan), do not report any similar joint development of high-tech instrumentation with industrial suppliers to what has been described for European ALL-RIs. In both cases, they only refer to a "joint development with industry" in which they provide access to synchrotron radiation for a company to test/modify its products.

Hidden Technology Transfer

Hidden transfer of knowledge can occur between beam scientists, beam engineers and industrial suppliers of instrumentation (the supplier company receives free advice from RI staff about how to develop their products). Such hidden technology transfer can be harmful to the RI, and it is difficult for an RI's Technology Transfer Office to control/regulate this. RI scientists should be aware that their knowledge can be used to generate profit for a private company and that there should be a return from the company for collaborating, so the implementation of non-disclosure agreements can be necessary.

On-site Expertise

Some ALL-RIs report that much of their development is done on-site by their own staff, for example ESRF has its own undulator manufacturing laboratory, so joint development with industry rarely occurs. The facility's own expertise is often provided to other facilities; ESRF develops and builds undulators for other ALL-RIs as well. This kind of knowledge about the location of such expertise is common knowledge within one community, but possibly not between the laser and accelerator communities. Exchanging this expertise knowledge could be a starting point for stimulation of innovation.

Further Observations

The networking between the technological transfer officers at different RIs on joint development is limited. Another limitation to the diffusion of information comes from the high degree of confidentiality of project information - RIs frequently do not have the right to disclose even general information like e.g. with whom they are working and in what field. It is recommended that facilities ensure in future industrial collaborations that they reserve the right to disclose this type of general information. A database could be established to exchange this information, at least after the industrial collaboration is complete. Feedback from the high-power laser community, with strong networking activities (for example Laserlab-Europe) could support the development on this area. Increasing the visibility of companies whose products have been developed via collaboration with an ALL-RI might increase the economic impact of ALL-RIs.

Enabling recognition of which ALL-RIs have contributed to new/improved commercial products, in the case when the ALL-RI contributed know-how but does not own any IP or share of the company, might allow that policy makers/funding bodies recognize the role that the ALL-RI plays in economic development.

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4.2 Protection and commercialization of intellectual property

The development of advanced technologies is recognised worldwide as a key factor in long-term successful economic development. Research in general and the RIs in particular have a crucial role to play in this sense. Scientists at ALL-RIs often develop new devices and new processes that have the potential to be commercialized. Examples include sample holders or sample environment systems, developed at the ALL-RI to allow a certain measurement to be performed, which would not have been possible with existing technologies. Another example of such inventive activities and developments are new undulator systems or other pieces of x-ray beamline technical equipment, developed by staff of an ALL-RI for their new beamline, and which can be of interest to similar facilities.

The RIs' innovation potentials are closely related to their capability to file patents. These are necessary to protect their intellectual property and to give confidence to industrial partners. Filing a patent can be fast, and it can also be rather cheap at the beginning. Related publications can be submitted as soon as the patent is filed (usually after around four weeks). The patent can become very expensive later and this intermediate period must be used to decide if the patent will be extended or abandoned. Collaborative research, joint labs or spin-off companies are not alternative to patenting. They can only be implemented if the intellectual property has been patented.

Inventive activities are encouraged by the ALL-RI's Technology Transfer Offices (TTO), which support commercialization of the intellectual property (IP) via patenting and selling of a license, or establishment of spin-off companies. The number of patents produced, licenses sold and spin-offs created can provide a direct measurement of the economic impact of the RI, and are of great interest to the RI's funding bodies.

Technology Transfer Offices

The RIs interviewed all have a TTO that takes care of intellectual property, commercialization and spin-off companies. The TTO is generally a department, division or group that is part of the RI's own administration, but at a few RIs (such as ELI-NP) these issues are handled by external agencies. MAX IV's technology transfer is handled by Lund University's TTO (Lund University Innovation) while PSI's TTO works in close collaboration with a large umbrella organization for Switzerland Innovation called PARK INNOVAARE. At ELI-Beamlines, the Center for Innovation and Technology Transfer (CITT) is a department within the ELI Beamlines section of the Institute of Physics (of the Czech Academy of Science), with its primary mission dedicated to the ELI-Beamlines facility. The CITT also partly supports other units within the Institute of Physics, but not external entities. HZDR has created a private company, HZDR Innovation GmbH, fully owned by HZDR, to act as a profit centre for its spin-offs.

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Requirements from funding agencies

DESY, ELI-ALPS, ELI-Beamlines, HZDR, LU/MAX IV, PSI recognize a requirement from the government/funding agencies to report their number of patents. In some cases, the TTOs are required to send statistics to the facility directors, but the TTO staff themselves do not know how the data is used or what is then reported to the funding agencies. Statistics about patents and IP were not considered important for ESRF, Elettra or SOLEIL, as academic publications are the primary interest of the government/funding agencies.

Support of Spin-Offs

At DESY, Elettra, HZDR, LU/MAX IV and PSI, the TTO is able to provide full support for an employee to patent his/her work, perform market research, acquire seed money to start a spin-off company, and continues to monitor the spin-off as its progress develops and can also assist in attracting private investment. ELI-ALPS and ELI-Beamlines also anticipate that they will provide this service to their scientists (a service that will likely be also available at ELI-NP once the ELI-ERIC is established). ESRF has a separate Innovation Center/Incubator in the vicinity that takes care of this directly. At SOLEIL, spin-off creation is not a priority.

These findings reflect two different models:

1. The RIs provide full support to innovation and commercialization of innovative solutions generated by the researchers and engineers of the RI;
2. The RI focuses on research, while local/national offices/services are used to provide this support.

It is common across the RIs be embedded within a surrounding “Science Village” – an area with many scientific institutions and start-up companies in close proximity. Those RIs that do not already enjoy such an environment have reported plans to initiate such developments.

Types of Spin-Offs

The RIs interviewed reported spin-off companies selling undulator systems, fast x-ray cameras and novel x-ray detectors, nanopositioning systems for synchrotron experiments, femtosecond lasers, laser synchronization systems, UV lithography technologies, as well as (in one instance) science communication services (including graphic design). PSI could list up to nine spin-off companies, but only four of these were related to its synchrotron or FEL light sources. PSI does have a unique experience with two spin-off “contract research” mediator companies that provide access to synchrotron radiation measurements for industrial users. This is a very innovative idea and is further described in Section 4.3.

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Motivation of scientists for commercialization

DESY and PSI organize events such as internal workshops for how to commercialize IP and create spin-off companies. A major finding raised in this study is that many scientists are not interested in or are unwilling to protect or commercialize their inventions. The priority of a majority of scientists is to publish or develop new projects, rather than on commercialization of their results. This raises the issue of publication vs. commercialization vs. spreading common knowledge and advancing research. This is a very important aspect of innovation, IP protection and open research – for the TTOs and also of prime relevance to the researchers.

R&D collaboration with Industrial Partners

DESY and HZDR's TTOs, as well as the TTO representing ELI-NP described cases in which they had been approached by industry to provide know-how/support in developing a new product for commercialization, for example a vacuum pump or laser equipment. DESY also has invented some new materials and allowed a company to develop them into a commercial product.

Open Innovation

The TTO offices unanimously testified that they face requests from the industry for clearer strategies on IP protection. Open innovation only seems to be welcome by both RIs and industry for software development projects. The TTOs follow the requirement of the target industry (for example pharmaceutical, chemical) in terms of intellectual property policies. MAX IV described a case in which a life-science researcher did not want to commercialise his invention, and he published his work. This disclosure prevented his discovered technique from coming to market as the target industry was unwilling to make use of the technique without ownership of the intellectual property.

Japan and USA

The situation in Japan contrasts that in Europe, as SPring-8 reports that they have no metric for reporting economic impact to their funding agencies, outside of industrial access to its instruments. They have no activity in generation of patents, spin-off companies or a Science Village/Innovation Centre. Brookhaven National Lab also has no metric for reporting economic development to its funding agencies but has an intellectual property office that helps support any spin-offs. Neither SPring-8 nor Brookhaven National Lab reported any interest in a regional ecosystem of academic institutions, high-tech companies and spin-offs.

Clusters

Very few RIs report about working together with other institutes on strategic measures to address intellectual property, only HZDR does this (as part of the Helmholtz Society).

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National and international patterns

The surveyed RIs show that their approach in supporting innovation issues is rather inhomogeneous and a few RIs see significantly less drive than others. Those RIs which reported a lower drive for protection and commercialization of IP (Elettra, ESRF and SOLEIL) tend to be much more active in providing commercial access to their instrumentation.

4.3 Commercial access to advanced laser light sources

Statutory commitments of most ALL-RIs towards their stakeholders require that a percentage of the available beamtime is made available, against compensation, for proprietary research (most of the time to industrial users). This is another activity in which ALL-RIs contribute to economic development – as companies will have access to the ALL-RI's state-of-the art scientific analysis tools and techniques, enabling them to optimise their products or production processes, and gain an edge over competitors.

The mission of the ALL-RIs is largely focused on fundamental research, so to satisfy the requirement from the stakeholders the ALL-RIs allocate available beamtime to industrial use. The majority of scientific research being performed at ALL-RIs is aimed at scientific excellence (the main beamtime allocation criterion) and the need to produce scientific publications, whereas industrial activities have a minor role.

This commercial access to an ALL-RI, in which an industrial company pays an access fee to have experiments performed at a beamline/instrument, is different from the industrial access via a peer-reviewed selection process as is most usually the case of a collaboration between industry and academia. In the latter case, there is obligation to publish the results. Most RIs recognize that a significant amount of industrial access follows this model, and many ALL-RIs do not currently have statistics to measure how many of their academic users are working with industrial partners. DESY implements this via a survey within their user access portal. SPring-8 reports their total amount of industrial use (peer-reviewed and proprietary) is as high as 20% - but only 2% of beamtime is actually sold to industrial customers. It is recommended that RIs maintain a quantitative analysis of how much academic beamtime is accessed by user groups with industrial collaboration, as this might be a major indicator of RIs' contribution to innovation.

The interest of industries in commercial use of ALL-RIs mostly arises from the need to analyse materials using techniques not possible using lab sources, such as x-ray absorption spectroscopy and protein crystallography, and in particular applications of x-ray diffraction, scattering and spectroscopy (including infrared and UV), where synchrotron or laser characteristics are absolutely required. In many cases, industrial researchers do not have experience in running an ALL-RI measurement themselves, or even performing analysis on the results of the experiment. For this, ALL-RI staff members prepare the samples, perform the measurements, analyse the results and prepare a report for the industrial customer.

Representatives of industrial liaison offices (ILOs) from each of the EUCALL consortium's members, plus several external facilities, were interviewed about the level of support provided for commercial access of industrial companies to the facilities' instruments and beamlines. The majority of facilities represented in this study are located in Europe, with one each from USA and Japan for benchmarking purposes.

While ILOs of synchrotron facilities, FELs and optical laser facilities have been interviewed, only synchrotron facilities were able to provide details about well-developed access policies for industrial users. This is because synchrotron facilities have a well-established history of industrial collaboration, while the relatively new FEL and optical laser ALL-RIs do not yet have a strong collaboration with industrial users. With the current build-up of ELI and European XFEL, it is hoped that these facilities will also provide service to industrial users, starting from 2018-2019, and so one possible outcome of this report is for the future ILOs of ELI and European XFEL to learn from the "best practices" of the ILOs of the synchrotron ALL-RIs.

Due to confidentiality agreements between ALL-RIs and their industrial users, full disclosure about industrial customers and the measurements performed are not available. Many commercial users sign non-disclosure agreements with the ALL-RI to protect their intellectual property. In some cases, the access-fee for an industrial measurement can be reduced if the industrial user agrees to publish some/all of the results of the measurement.

Support of industrial customers

Different RIs offer various degrees of support for industrial access. Most agree that the percentage of all beamtime sold to industrial users should lie around 2 – 5%. It is also recognized that according to their scientific profile and the techniques offered, some beamlines will have no industrial use, while others will be much more industrially relevant. The RIs recognize which of their instruments/beamlines are the most industrially relevant and focus on promoting them.

Out of Europe, the case at SPring-8 (Japan) synchrotron radiation facility is interesting for a comparison, as SPring-8 operates three industrial beamlines directly funded by industrial companies, such as Toyota, thanks to a strong support of the government to the industrial users' access program.

Most RIs allocate shifts of beamtime for industrial measurements at each instrument during periods of operation and, when no industrial measurement is planned, this time is most often used by the beamline staff members for their own "in-house research". Therefore, most RIs can schedule the industrial measurement within 4-6 weeks of the initial contact with the customer. The possibility to access the ALL-RI relatively quickly is considered a strong argument for the industrial users to purchase beamtime, rather than access the ALL-RI via peer-reviewed academic collaboration, for which beamtime can be accessed months or sometimes even a year after the proposal is submitted.

Laserlab-Europe provides access to industrial users, but as a consortium via a peer review proposal process and free of charge, thus not what this chapter addresses. Laserlab-Europe has an Industrial Advisory Committee promoting industrial user of the laser RIs within its consortium. Many individual partners within Laserlab-Europe, provide commercial access as part of their national access programme, for example CLF in the UK.

Industrial Measurements at Synchrotron Facilities

Almost all RIs interviewed reported that the most industrially relevant technique is protein crystallography, with a major part of their industrial beamtime sold to pharmaceutical or biotechnology companies (Life Sciences). In general, the next most relevant techniques (in descending order) are x-ray absorption spectroscopy, x-ray powder diffraction, x-ray scattering and imaging. The most relevant industrial fields for commercial use of synchrotron radiation, after Life Sciences, are Automotive/Construction, Nanotechnology, Catalysis, Energy, and Food Science. While it was difficult to obtain concrete statistics about the studied RIs' industrial users, the Science Link project (www.science-link.eu) (2012-2014) involved a series of calls for proposals from industrial users for free commercial use of one of four synchrotron radiation facilities. The types of companies which applied for measurements are shown in Figure 1, while the type of measurements performed for each accepted proposal is shown in Table 1. It can be noted that Science Link results did not feature any protein crystallography measurements – which could be due to the fact that most pharmaceutical companies already have industrial contacts with synchrotron radiation facilities and were not interested in the "free" Science Link measurements from which the results were required to be published. Science Link also made limited efforts in outreach to these latter companies.

Figure 1 shows that the majority of applications came from companies in Construction and Engineering, Materials Science and Nanotechnology, and Life Science and Biotechnology (approximately 75% of all applicants). From Table 1, 16/49 (33%) of the accepted measurements required x-ray diffraction (XRD) and 12/49 (25%) required x-ray absorption spectroscopy (XAS) techniques. Science Link's results generally support the results of

EUCALL's surveys at the synchrotron sources. XRD and XAS are the most important synchrotron techniques for industry, after protein crystallography. Companies in Construction and Engineering, Materials Science and Nanotechnology, and Life Science and Biotechnology have the highest demand for synchrotron radiation techniques.

Industrial Liaison Office

The industrial liaison offices (ILOs) of the different RIs studied have varying staff numbers and strategies. Some RIs employ dedicated Industrial Liaison Scientists (ILSs) (often former beamline scientists) to perform industrial measurements, as well as to work in publicity/marketing for the industrial service. These scientists also support regular scientific work at the RI and participate in in-house research when they are able. Other RIs employ no industrial scientists, and it is the task of beamline scientists to perform industrial measurements and sometimes contribute to marketing activities.

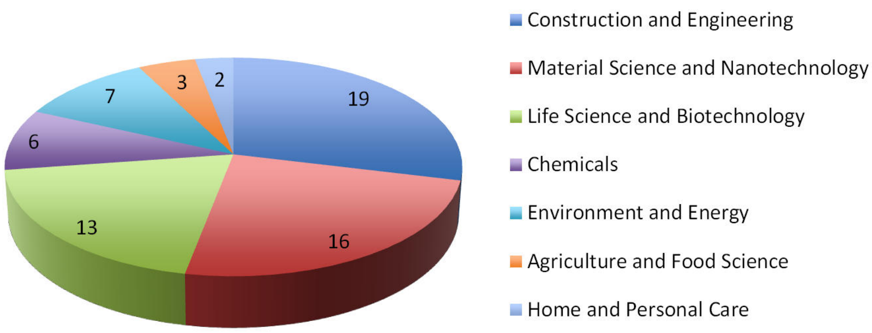

Figure 1: Industrial Category from which Science Link's 66 applications for synchrotron analysis came.

	XRD	XAS	SAXS	Tom.	PEEM	IRS	UV/VIS	XPS	Lab	Total
Agriculture and Food Science	2	1	-	-	-	-	-	-	-	**3**
Chemicals	1	1	-	1	-	-	-	-	1	**4**
Construction and Engineering	7	1	4	1	-	-	-	-	-	**13**
Environment and Energy	1	2		-	1	1	-	-	-	**5**
Home and Personal Care	1	-	1	-	-	-	-	-	-	**2**
Life Science and Biotechnology	-	5	-	3	-	1	1	-	-	**10**
Material Science and Nanotechnology	4	2	-	-	2	-	1	2	1	**12**
Total	**16**	**12**	**5**	**5**	**3**	**2**	**2**	**2**	**2**	**49**

Table 1: Synchrotron technique and industrial category of Science Link's 49 accepted industrial proposals.

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Diamond Light Source has a well-established and active Industrial Liaison Office. 5% of all beamtime is industrial, with Industrial Liaison Scientists employed full time at Diamond to perform industrial measurements and the subsequent data analysis and reporting. Each ILS is a specialist (having a PhD) in one or two of the x-ray techniques offered to industrial users. The access fees paid by the industrial users are the main source of Diamond's funding to pay the ILSs' salaries.

Elettra's ILO is managed by a former beamline scientist (BLS) and supported by three staff members who have backgrounds in economics, marketing, and administration. Elettra's own BLSs are usually responsible for actually performing industrial measurements, which make up 1% of Elettra's user beamtime.

ESRF has three ILSs who liaise with industry and perform industrial measurements. These employees are usually dual-tasked staff with regular support/development duties on the beamlines, as well as industrial access related work. Regular BLSs also contribute to industrial access support work as well across the beamlines. ESRF's directorate does not require a particular amount of beamtime to be sold to industrial users, but the current level of industrial proprietary access is around 2%.

PSI reserves 10% of the available beamtime for industry. All the proprietary access to the beamlines is managed by the SLS Techno Trans AG, a private company. Services are provided either by PSI spin-off mediator companies (*Expose* for protein crystallography and *Excelsus Solutions* for materials science) or by the corresponding BLS.

SLS Techno Trans AG was founded in the late 1990s, before operation of the Swiss Light Source (SLS) started. When the SLS was built, the PSI management wanted to raise the awareness within the industrial community of the potential of the new facility. SLS Techno Trans AG was created to give to this action a higher visibility and to increase the impact of the marketing operations. From the point of view of its operations, the company has no employees and no costs. When an industrial company is interested in working with the PSI, depending on the complexity and duration of the requested tasks, the TTO of the PSI will identify the right expertise to fit to the need of the customer. The entity providing industrial service depends on the requirements of the customer:

- if the industrial company requires measurements including data analysis, a mediator company like Excelsus (e.g. for material science beamlines) will sell the service to the customers (Excelsus will buy the beamtime from SLS Techno Trans AG to access the synchrotron beamlines);
- if the industrial company requires measurements including data analysis, and an appropriate mediator company isn't available, SLS Techno Trans AG will sell the

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service to the customer, if a beam-scientist at PSI capable to perform the requested measurements is identified;

- if the industrial company wants to start a long-term partnership, a collaboration agreement is signed directly between PSI and the customer. The access costs paid by the industrial customer contribute to the salaries of the beam-scientists involved and the equipment on the used beamline.

Almost all beamlines at PSI are reported to have some industrial access, and a few, like those for protein crystallography, have up to 30% of industrial beamtime. The generated revenues are in general equally shared between the Directorate, the Division and the beamline. An exception is for long-term partnership programmes where, except for a small percent of overheads, the revenues are totally dedicated to the beamline staff and equipment.
The actual model of the industrial access to the SLS facility is strongly dependent on the visibility of the capabilities of the beamlines within the industrial community. To enhance this visibility, the TTO intends to support the creation of further spin-off companies (like Excelsus or Expose) for each of its beamlines having high potential of industrial applications, for more efficient marketing and to sell a complete service to the customer.

During 2016, neither DESY nor SOLEIL employed an ILS, however while DESY had 1-2 actual industrial measurements per year, SOLEIL maintains around 2-3% of the available beamtime for industrial measurements. These are performed by BLSs who are willing to collaborate or work on industrial projects. At DESY, BLSs have been required to perform all samples preparation, measurements and analysis for the industrial users.

In 2017, DESY restructured its industrial liaison office with the employment of two ILOs and an ILS (a BLS who now works 50% as ILS), and made a reduction of its previously higher than average hourly cost of beamtime. In 2017, DESY had 5% of the beamtime of its biological imaging and diffraction beamline sold to industrial users, following the employment of an ILS at this instrument. A goal is to increase the industrial activity and employ this scientist 100% as ILS. It can also be mentioned that at DESY, many biological investigations performed at the PETRA III synchrotron are actually made using three beamlines that are run by the European Molecular Biology Laboratory (EMBL) while measurements in construction and engineering are run on instruments operated by the Helmholtz Zentrum Gestaacht (HZG). Both EMBL and HZG have their own ILOs and ILSs, which perform industrial measurements at their beamlines at PETRA III – for which DESY receives a part of the industrial access fee. DESY also sells industrial access to its “machine” (i.e. the electron accelerators, accessed by companies that produce components or devices used in particle accelerators and which require testing with an operational accelerator). It is estimated that DESY’s industrial use of the machine has an equal number of users (or slightly more) than for the industrial use of

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beamtime at PETRA III, and DESY intends to also employ an ILS for this kind of industrial service, as well as further ILSs for other synchrotron techniques.

SOLEIL places an emphasis on maintaining an annual renewal of industrial customers equal to 10%-15%. The effort to find new customers is important and is estimated to be ten times more important than to maintain an existing customer. Each new customer passes through four steps: commercial contact, feasibility studies (short time and for free), confirmation test (paid for and in real conditions), repeatability test (paid for and in real conditions).

The ramp-up to reach the actual steady state (10-15% renewal rate, 90-85% recurring industrial users) lasted three to five years, starting in 2008. Two application engineers are employed full time to support industrial access: bio-crystallography for pharmaceutical industry and material science (x-ray diffraction and tomography). For the other beamlines, the beamline scientists dedicate a few percent of their time to the industrial access.

At NSLS-II (USA) the industrial access program is developed via direct collaboration of the beamline scientist with the industrial scientist. This approach is facilitated by the high mobility of the researchers between industry and public research, which is less common in Europe.

Access Models

All RIs offer feasibility studies to potential industrial users, which involve up to one or two hours of free beamtime to determine whether a company's intended measurement could be successful at the RI.

The interviewed RIs each provide a "mail-in" service, during which RI staff perform all measurements and analysis for the industrial customer. RIs also have an access model in which the industrial company pays for the beamtime and the company staff come to the ALL-RI and runs the experiments on site, with some level of support from the BLS. This depends on the experience and capabilities of the industrial users themselves.

Standard cost models at synchrotrons are approximately 500€ per hour of beamtime, with extra costs of 150-200€ per hour of scientific support. In most cases, an entire eight-hour shift of beamtime must be booked by the industrial user. At RIs with a high number of simultaneous industrial measurements taking place, an eight-hour shift can be shared between different companies, when there are several industrial measurements scheduled that require the same instrument.

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Outside Europe, the cost for access to both NSLS-II (BNL, USA) and to SPring-8 (Japan) as examples is also in the range of 400-500€ per hour.

Commercial access for FELs is foreseen to cost in excess of 5000-20000€ per hour of beamtime, depending on the type of FEL (UV or x-ray).

Research Infrastructure	Type of RI	Beamtime sold to industrial users	Scientific/Non-scientific personnel of the ILO[2]
DESY	SR & FEL	[SR] <1% in 2016, ideally 5% [FEL] one Expt. since 2005	1/1 – [increased to 2/4 in 2017]
Diamond Light Source	SR	5% current, maximum 10%	10/1
Elettra	SR & FEL	[SR] 1% [FEL] 0	1/3
ELI-ALPS	Optical laser[1]	5% (plan)	n.a.
ELI-Beamlines	Optical laser[1]	5-10% (plan)	n.a.
ELI-NP	Optical laser[1]	n.a.	n.a.
ESRF	SR	2% current	4/0
European XFEL	FEL[1]	n.a.	1/1
HZDR[3]	Optical laser[1]	undefined	1/11
MAX IV Lab.	SR[1]	n.a.	1/0
PSI	SR & FEL[1]	10%	1/2
SOLEIL	SR	2-3%	2/1
Brookhaven National Laboratory	SR	n.a.	1/0
SPring-8	SR & FEL	[SR] [FEL]	9/1

Table 2: Collected information about industrial access to the RIs

[1] Light-source under construction during data collection

[2] In some cases, no employee is specifically employed to work in the ILO, but some other staff member spends a portion of the working time working in the ILO.

[3] HZDR provides commercial access to instrumentation such as at their centre for ion beam physics - ion implantation and irradiation, ion and plasma-based deposition as well as ion beam analysis.

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Motivation of RI Scientists to cooperate with Industry

At several RIs the BLSs are not highly motivated to perform industrial measurements, especially to perform the “mail-in” service where samples are provided and the BLS performs measurements and data analysis on work that results in no publication and often no financial gain to the beamline/instrument. SOLEIL’s achievement in maintaining 2-3% industrial measurement with a relatively small team (2-3 full time employees at the industrial liaison office) could be due to the fact that beamlines involved in industrial measurements receive an additional budget, coming from the industrial access revenues, to improve the beamline or to fund short-term positions.

Marketing/outreach with industry

Each RI has its own marketing activities to reach the industry. The activities range from thematic workshops organised for a special user community to specific, one-to-one visit and projects for an industrial partner. At PSI, BLSs participating at scientific conferences are required to add some content about the offer for industry to their scientific presentations, however the effectiveness of this is limited if there are no industrial representatives present in the audience.

Workshops and training programs for industrial researchers are organised by Elettra, ESRF and other RIs but are reported to have limited success in attracting real contracts. DESY’s restructured industrial service group organised a specialized Industry satellite meeting to the DESY/XFEL User Meeting 2018 entitled “Benefit of synchrotron light sources for industry” during January 2018, at which industry representatives were invited and presentations were held about DESY, EMBL and HZG’s offer to industry as well as examples of previous industrial collaborations.

Despite these activities, a common bottleneck is the lack of knowledge within industry about what is possible at advanced light sources. Even industrial researchers with knowledge of conventional x-ray techniques may not know about the application of a synchrotron to their application, and even less about the possibilities at FEL and optical laser RIs. A challenge for the future will be to create better awareness within the industry for analytical and research possibilities at RIs. Several other RI cluster projects are involved in this. MAX IV’s current strategy of collaboration with existing clusters of industrial companies is an interesting approach and its success should be monitored.

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External service providers / Mediators

PSI, MAX IV and ESRF collaborate with external service provider / mediator companies:

- Excelsus Structural Solutions (PSI spin off) – XRD
- Expose (PSI spin off) – Protein Crystallography
- Colloidal Resource Limited (Lund) - SAXS, EXAFS
- NOVITOM (Grenoble/Saclay) - X-ray Imaging

These companies employ PhD level scientists with experience in experimental techniques at the radiation sources. The companies perform their own marketing and consultancy and, in some cases, have their own lab sources for some analysis on site. When the mediator has a contract with a customer for a project requiring synchrotron radiation analysis, the mediator buys commercial beamtime from an ALL-RI, can perform measurements and data analysis and prepare the reports. Often the mediator company is able to develop a long-term contract with specific light sources for simplified regular access.

Collaboration with such mediator companies is very beneficial to light source RIs, especially to those RIs with small industrial liaison offices. The mediator companies reduce the workload required by the RI staff to perform marketing and outreach, to run the measurements and to do the analysis. RIs can be recommended to form close collaborations with these companies, and to consider supporting start-up mediator companies (for example in their own region) if possible.

Industrial applications of FELs

Industrial measurements at long-term operational FELs (FLASH and FERMI) are not yet well established. It would be useful to develop concrete examples of industrial applications of FEL radiation. The recognised need of pharmaceutical companies for synchrotron protein crystallography measurements could provide a first step towards this. Usually a limitation in successful protein crystallography measurements is the difficulty in preparing suitable protein crystals. FELs allow analysis of much smaller crystals, and even single biomolecules. Therefore, FELs may allow industrial users to solve the structures of biomolecules for which synchrotron-based protein crystallography is not applicable.

A further method to develop industrial applications of FEL radiation is to examine the work done at LCLS and SACLA, as well as at the infrared FELs operating in Europe – which industrial measurements did these facilities have so far? Scientific output of these FELs could be studied, in order to find examples of research which that have industrial applications. In this case, direct communication with industrial experts would be very helpful.

Additionally, industrial application of the photon beams foreseen at ELI's RIs may also require a similar development.

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European Projects addressing Industrial Access at RIs

- The Science Link project (2012–2014) is an example of how a network of RIs (four synchrotrons in this case) collaborated to attract 49 industrial customers during two years, by offering free measurements. This demonstrated that the need exists in the industrial community for access to RIs, but an important outcome was that beamtime was usually too expensive, especially for SMEs. This is a primary reason that most of the engaged companies did not return for commercial beamtime, as well as due to the fact that three out of four of Science Link's light sources (DORIS III, PETRA III, MAX-Lab) were shut down during or directly after the project. (www.science-link.eu)

- Baltic TRAM (2015-2019) is the follow-up project to Science Link and is led by DESY. Within this project, "Industrial Research Centres (IRCs)" are established in each country of the Baltic Sea Region. The function of these IRCs is to assist local companies to solve their scientific problems by first accessing laboratory equipment in local universities and other academic research facilities (for example lab source x-ray diffractometers, scanning electron microscopes, mass spectrometers etc.). When the industrial company's scientific analysis is sufficiently developed within the IRC, if needed, Baltic TRAM's funding can be used to purchase industrial beamtime at DESY for more advanced analysis. (www.baltic-tram.eu)

- The NFFA project (2015-2019) promotes industrial access to up to four European synchrotrons (DESY, SOLEIL, PSI, MAX IV/LU) and other nanotechnology research facilities. Access is coordinated through a single-entry point at the NFFA.eu portal, through which users will dialogue with a team of experts in the fields of their interest, building a personalized access programme. The Technical Liaison Network, industry and business development staff of the NFFA-Europe nodes aim to develop understanding, awareness and efficient access for industry. This is a consortium-wide activity, as well as enabling each node to perform its own outreach to industry in its regional ecosystem. To help build the case with industry incentivised knowledge transfer allows the development of industry experience through feasibility and pilot studies on the NFFA-Europe facilities. (www.nffa.eu)

- SINE2020 (2015-2019) offers free industrial access to a cluster of European neutron research facilities, with an "open call" model similar to that of Science Link. (www.sine2020.eu)

- The ACCELERATE project (2017-2020, involving CERIC-ERIC, ELI-DC and others) has a work package with the goal to develop policies and procedures for commercial access, to be embodied in sets of model documents (commercial access/service contracts, NDA/CDA, IP agreements, etc.), which will be compiled in a handbook of commercial access, which would be further reusable by other RIs. The partners will organize and attend a number of research-to-business events, to build and maintain industrial networks, by fostering the interaction with industry and, in particular, with SMEs. They also will train TTO staff with scientific, legal and economic backgrounds. Target events will be organized, to re-link R&D staff from the industrial sector with the research environment, for promoting awareness of RIs, their instrumentation and of the available modes of commercial access. (www.accelerate2020.eu)

- CALIPSOplus (2017-2021) is a large network of all synchrotron and FEL sources in Europe. For support of commercial users at its RIs, the project has one networking activity called "European Light Sources for Industrial Innovation (ELSIIplus)" which aims to affect:
  - Cultural developments: bring about change in industry attitude to light sources, and in a more common approach for light source to work together for industrial research and innovation.
  - Build capacity in industry, particularly SMEs, to use light sources for their research and innovation needs.
  - Test and validate: generate real world industry/SME access and light source exemplars.

  CALIPSOplus will also develop an access program: "Tailor-made for SMEs Trans-national Access (TamaTA)". (www.calipsoplus.eu)

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5. Conclusions, recommendations and future activities

This section summarizes the most important conclusions and recommendations for the two main activities addressed in this report. It furthermore addresses the issue of sustaining activities which have been initiated within EUCALL and shall be continued well beyond the duration of the EUCALL project.

5.1 Analysis of and opportunities for the combined research potential of EUCALL facilities

The EUCALL spreadsheet "UV/x-ray Instrumentation at ALL-RIs", collected in order to establish a common understanding of the present situation and research opportunities at the ALL-RI facilities, has turned out to be a very valuable tool to analyse current status and opportunities for future research directions. Both, internally and by the external expert users and the EUCALL SAC members, the data collection was considered so valuable that it will be developed into a tool for users and facility operators. This tool will provide the possibility to select and oversee the large number of beamlines/instruments available at the ALL-RIs for user-driven research applications. The integration of the data into the searchable Wayforlight database (see Section 5.3) leads into a first activity that will sustain well beyond the duration of the EUCALL project. The interest by the EUCALL partners and external partners, but also by the Wayforlight operators, indicate how timely the EUCALL activity to collect and make available information about different types of light sources in an integral fashion has been. This collection and the extended Wayforlight database demonstrate convincingly how the European research landscape not only changed quantitatively, but also qualitatively.

The analysis of the facility data, based to a large extent on the feedback of expert users of the EUCALL facilities, indicates potential avenues of making the use of the ALL-RI facilities even more efficient and of optimizing research opportunities offered by the ALL-RI facilities:

- Develop the beamlines/instruments at the upcoming FEL and optical laser sources in a way that they provide a wide range of techniques and sample environments responding to specific user needs, similar to what is currently already achieved at synchrotron RIs.
- Develop the new laser-based and FEL sources in a way to reach an accuracy regime provided today only by the synchrotron facilities.

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- Enhance the provision of complementary methods at the ALL-RI beamlines/instruments, based on e.g. near visible optical laser or electron techniques, in order to study samples using different techniques.
- Ensure that the full spectral range from the UV to hard x-rays is accessible for state-of-the-art research using ALL-RI facilities.
- Exploit the availability of different types of light sources to gain more complete information about sample dynamics, e.g. by studying different time scale processes using HHG, FEL and SR sources; or physical phenomena, e.g. by studying light-matter interaction in different parameter regimes of photon energy and/or intensity.
- Exploit synergies of laser and accelerator communities in developing new compact sources to be employed by users at their home institutes for preparing experiments at the large scale facilities.
- Engage in joint developments of sample environments and end-station instrumentation to provide efficient state-of-the-art instrumentation at many instruments, thereby contributing to a more efficient use of the facilities. Users will appreciate identical and standardized equipment and joint developments will enable enhanced staff training and exchanges.
- Provide extreme conditions researchers access to targetry facilities and co-locate high energy lasers with high resolution hard x-ray sources to enable access to new pressure and temperature regimes.

The analysis of the operation of ALL-RI facilities for users indicates that the presently employed schemes for peer-review and allocation are considered highly efficient and do not require major alteration. Too low and too high oversubscription rates are considered not optimal and should be addressed by facility managements. Transfer of proposals from one facility to another are considered impractical at present, at least for those user facilities running their own dedicated and optimized proposal review process. The exchange between User Offices of ALL-RI facilities has been considered very important in order to create similar standards for user access and proposal review.

5.2 Promotion of innovation from a combination of RIs

While Industrial Liaison Officers of synchrotron radiation, FEL and neutron sources regularly meet and collaborate, EUCALL's workshop "Innovation Potential of Advanced Laser Light Sources" was the first such meeting to discuss matters of technology transfer (outside of commercial access policies) and the meeting was very positively received by the participants. This was particularly the case for the representatives of the new facilities, European XFEL and ELI, who were able to build up networking connections to their counterparts at the operational RIs. It would be worthwhile to create a network for the TTO offices, to facilitate

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the exchanges and the synergies on the different topics, especially on the training of scientists for entrepreneurship.

In recognition of the diversity of approaches to technology transfer at the different RIs within EUCALL, it is recommended to develop, or recognize, a charter (or an embryo for a future charter) in technology transfer policies.

Joint development of technology

To reduce "hidden technology transfer" between RI staff and industry (where the industrial partner receives free advice from RI staff about how to develop their products) it is recommended that non-disclosure agreements are implemented between the parties.

Knowledge about the location of on-site expertise at an RI is common knowledge within one community, but possibly not between communities, such as between the laser and accelerator communities. Exchanging knowledge of such expertise could stimulate innovation and cross-pollination of ideas between communities.

It is recommended that RIs ensure in future contracts with industry, that they reserve the right to exchange general information with other facilities about with whom they are working and in what field. A database could be established to exchange this information, at least after the industrial contract is completed.

Increasing the visibility of companies whose products have been developed via collaboration with an RI might increase the economic impact of RIs. Enabling recognition of which RIs have contributed such new/improved commercial products, in the case when the RI contributed know-how but does not own any IP or share of the company, might allow that policy makers/funding bodies recognise the role that the RI plays in economic development.

Protection and commercialization of intellectual property

The key obstacle to overcome lies in the motivation of RIs' researchers to engage the technology transfer office when they have a discovery or invention that has a potential commercial application.

Training of the researchers about processes involved in protection and commercialization of intellectual property is imperative in developing the innovation potential of RIs. If this is not immediately implementable, it is recommended to strive to obtain the funding needed for such systematic training programs of the early career stage researchers.

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It is noted that the Partnership for Innovation, Education and Research (PIER – a partnership of the Hamburg University and DESY) runs an annual PIER Innovation Day, which is a workshop for early stage researchers in which these topics are presented from the perspective of Innovation in Hamburg. This event could be an example for how other EUCALL RIs could train their young researchers, and could be an area in which a cluster of RIs organizing a joint training program could benefit most greatly.

In parallel, it is not recommended that an RI patents every single invention that it develops, simply for the sake of generating of a large number of patents. It is suggested that Technology Transfer offices carefully evaluate the developments and advise researchers about which inventions should be protected and which are more suitable for direct publication.

Rather than simply counting how many patents an RI generates/holds, a much more useful approach could be to define a "key performance indicator" for the economic impact of an RI. This could reflect how many licenses an RI sells for its patents, the annual turnover of its spin-off companies, and their survival rate. The previously suggested network of TTO experts would be uniquely qualified to define this key performance indicator so that the economic impact of European RIs could be measured in a standardized way.

The success of RI spin-off companies could be improved if knowledge about the companies is disseminated within the network of RIs. Many RI spin-off companies specialize in photon-science technologies, so their main customers would be other photon science RIs.

A database of patents held by ALL-RIs could be established, so that patent-holders could more easily find researchers with similar interests at partner RIs for possible collaboration.

To promote innovative technological and scientific developments at Advanced Laser Light Sources, EUCALL also recommends the initiation of an exchange program, for example within a European project, to bring together different potential user communities to facilitate mutual comprehension. This approach could prepare a large, homogeneous community that can be efficiently informed of innovative results.

A common procedure within the European Union to let the companies and the RIs collaborate on the prototyping of projects would be very useful. The actual procedures must currently be negotiated case by case and this can be exhausting for a SME.

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Commercial access policies
Concrete examples of industrial applications of FEL radiation as well as of the secondary sources of UV/x-ray radiation produced at optical laser facilities should be developed such that those facilities industrial liaison officers can efficiently begin marketing to the relevant industry.

Commercial access to ALL-RIs via the use of mediator companies such as *Excelsus Structural Solutions* and *Colloidal Resource Limited* is considered a very important approach and the support of such companies is encouraged. A cluster of RIs could offer a special access scheme to these companies, which allows access to a diverse range of various synchrotrons, FEL, optical laser and also perhaps neutron sources.

A further suggestion is the establishment of an Industrial Advisory Panel consisting of experts in synchrotron, FEL, optical laser and neutron techniques who can provide advice on which techniques (from all sources) could be best for a given industrial problem, and which instruments/beamlines are most suitable. Such a panel can also help new facilities to become integrated as established RIs for commercial access.

The ongoing activities of the industrial service groups for clusters of RIs within Laserlab-Europe and the CALIPSOplus, SINE2020, NFFA and ACCELERATE projects are of high importance and demonstrate the benefit that the RIs achieve from collaborating. The planned future "Network of research infrastructure Industrial Liaison and Contact Officers (INFRAINNOV-02-2019)" within Horizon2020 is expected also to be an important step forward in deepening collaboration between RIs and industry.

5.3 Sustaining the activities initiated by EUCALL

There are several activities initiated by EUCALL that shall be continued beyond the duration of the EUCALL project. The most important ones are described hereafter.

Providing EUCALL data through the Wayforlight database
The incorporation of WP3's spreadsheet "UV/x-ray Instrumentation at ALL-RIs" into a publicly available database on the www.wayforlight.eu website is a significant step forward in harmonizing the landscape of photon sources in Europe. Users will be able to find information about instruments at both accelerator and laser-driven light sources which are suitable for their particular requirements. The extra datasheet incorporated for the external optical lasers present at a beamline will be very useful for ALL-RI users and adds a dimension to the database explicitly specific to EUCALL's focus on experiments combining UV/x-ray radiation with optical lasers.

It will become much simpler for RI operators to ensure that the data about their instrumentation is kept up to date on both their facility website and the Wayforlight database. EUCALL encourages involved RIs to add other instrumentation (not included in the original spreadsheet) to the database and to update their own facility website to display the data as shown in the Wayforlight database.

The modified database will stimulate the RIs to modify how the beamline characteristics are displayed on their own websites, and if implemented will increase standardization among all participating facilities. This will be highly beneficial to the optical laser facilities, as it was observed during the spreadsheet data collection that often the characteristics of generated UV/x-ray beamlines are not presented in a harmonized way on the RI websites. The updated Wayforlight database will allow these characteristics to be displayed on the RI websites in the same format as the synchrotron and FEL RIs will use.

The extension of the Wayforlight database will improve access for users, as all relevant instrumentation characteristics for synchrotron, FEL and optical laser RIs will be collected into a single database. It will also allow direct comparison between how similar techniques are supported at different types of facilities, which has the potential to encourage users to consider experiments at other facilities than those they primarily use.

EUCALL also encourages the partners of the foreseen LEAPS collaboration (see below) to incorporate into the extended Wayforlight database any instrumentation not included in EUCALL's WP3 spreadsheet, so that all characteristics photon science instrumentation at RIs in Europe will be presented to the users, RI operators and the public in a standardised, searchable way. Assuring a sustainable updating of this website should be a priority. Facilities evolve very rapidly, many new facilities (i.e. ELI) will see light in the coming years and easy access to this tool will be very beneficial to their efficient use by the community.

The League of European Accelerator-based Photon Sources

During the course of the EUCALL project, seven EUCALL partners have joined a much larger collaboration of 19 accelerator-based light sources in Europe. The League of European Accelerator-based Photon Sources (LEAPS) collaboration promises a common vision of enabling scientific excellence solving global challenges, and boosting European competitiveness and integration. Specifically, the LEAPS Partnership aims to:

1. Encourage and facilitate discussions and exchanges among its members on issues relevant to shaping the technology of and future science at accelerator-based light sources in a worldwide perspective. Promote a collective strategy across European facilities, including development of specializations at individual facilities.

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2. Engage with stakeholders and organizations such as the European Commission and National funding agencies in all matters relevant to the development and long term sustainability of synchrotron and FEL facilities with the objective of informing and shaping future policies and funding opportunities.
3. Engage with the current and potential user communities to discuss their respective needs and anticipate and meet future challenges.
4. Strengthen interactions with industry, to exploit more fully the potential of synchrotron and FEL facilities for industrial research and to develop and exploit enabling technology.
5. Cooperate with other Research Infrastructures engaged in the analysis and innovative use of materials and bio-structures, such as laser-, electron-, and neutron-based facilities.
6. Develop and periodically update a landscape document outlining the impact of European synchrotron and FEL facilities and needs for developments in order to meet the scientific and societal challenges of the future.
7. Develop and periodically update roadmaps and action plans for key technologies.
8. Support and promote:
    - Standardization of access procedures compliant with the European Charter for Access to Research Infrastructures;
    - Greater coherence in the developments of data-policy, -handling, -storage, -analysis, -access and the promotion of Open Science;
    - Education and training of students, scientists and facility staff;
    - Enhanced mobility or exchange of staff to facilitate career development and improve the supply of rare skills;
    - Communication and outreach to inform and educate the general public;
    - Sustainable means of transnational access to aid the integration of scientists from countries with less developed infrastructure for research and innovation
    - Development of common performance indicators (including socio-economic);

Many of these goals are in agreement with recommendations that were developed during the EUCALL project. EUCALL therefore supports the initiatives of the LEAPS collaboration and recognizes the overall benefit to the landscape of photon science in Europe that the LEAPS collaboration will deliver. In particular, the goal of LEAPS to cooperate with laser-RIs (Goal 5. in the above list) ensures that EUCALL's efforts to bring together the communities of accelerator- and laser-driven RIs will be continued on a larger scale beyond the end of the EUCALL project. Co-operations and activities initiated as part of EUCALL, relevant to LEAPS facilities and considering the cooperation with laser-based ALL-RIs, shall be continued in the various activities to be initiated within LEAPS. Such activities might include workshops about the joint and complementary use of RIs in solving identified scientific problems, the

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federation of ILO/TTO offices of the RIs, similar to that of the Users Offices of RIs, or the initiation of a IP-rights training initiatives at the EU level for early-career stage researcher.

EUCALL was the first initiative to get the ALL-RIs working more closely together and to share their common challenges. The great success of this collaboration indicates that this story is just starting and a channel is needed to maintain strong communication between the ALL-RIs beyond the duration of the EUCALL project. A possibility to be considered would be the creation of an international conference that brings together the actors of the ALL-RI, for example every three years in a way similar to the Instrumentation conference for synchrotrons and FELs or the AIRAPT conference for the High Pressure community. EUCALL's Joint Foresight Topics (Deliverable 3.4) will contain suggestions and concepts for joint development activities which EUCALL recommends for possible future collaboration between the LEAPS partners and the optical laser facilities such as ELI and Laserlab-Europe.

6. Summary and Outlook

The data collection and analysis performed within the activities of EUCALL WP3 have resulted in important recommendations for development of future instrumentation at advanced laser light sources, including high repetition-rate femtosecond-scale pulsed light sources in the VUV and soft x-ray range, and suggestions for complimentary experimental techniques to be made available at light source infrastructures. Concepts for possible synergies recognize the complimentary nature of HHG, FEL and synchrotron radiation and recommend that future light sources be installed in close proximity to complementary ones, encourage sharing of designs for end-stations between facilities, and suggest the implementation of ultrafast electron diffraction techniques at light sources.

The inclusion of optical laser-driven light sources such as ELI and members of the Laserlab-Europe consortium into the Wayforlight database will increase awareness among users and facility operators within both the accelerator and laser communities of the capabilities of each light source in Europe, and promote migration of users between the two communities. The new database will also implement standardization of how the participating light source facilities present the characteristics of their instrumentation to potential users.

Technology transfer experts at the participating facilities have benefited under the experience exchange workshop organized under EUCALL, and best practices developed from the surveys performed have been delivered to the facility staff. Recommendations to enhance the innovation potential within a consortium of RIs were developed, including the training of young researchers, the formation of industrial advisory panels and enhanced cooperation with external mediator companies.

EUCALL's recommendations for enhanced synergy and innovation between accelerator and laser based light sources will be formally presented at the joint foresight topic workshop "Future Strategies for RI Operation" (see Deliverable 3.4).

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Annex 1: Questions to Expert Users

The following survey was distributed to a group of expert users of European advanced laser light sources, nominated by the Synergy Board, for analysis of the spreadsheet "UV-x-ray Instrumentation at ALL-RIs". The responses have been summarized in this report (Section 3.1 and Annex 2).

Based on the information in the "Spreadsheet of UV and X-ray instrumentation at Advanced Laser Light Sources" and your own experience, please consider answering the following questions. Your response will be analyzed and anonymously incorporated into one of EUCALL's reports regarding the overall portfolio of instrumentation in this area.

1. *As an expert user of one or more of the RIs presented in the table, how do you define your domain of research?*
2. *Which instruments at which facility included in the table have you used for experiments?*
    a. *Are you a user of facilities which are not included in the attached table? Which ones?*
    b. *Can you describe your criteria when you select a specific instrument for an experiment?*
3. *With respect to the listed instruments at European light sources, do you see:*
    a. *good or satisfactory availability of instruments/RIs for your research,*
    b. *possible synergies amongst different RIs, or instrumentation at these RIs,*
    c. *any missing capability of instrumentation that would be relevant for your research? Can you briefly name these and identify if these are available at RIs outside of Europe?*
4. *Could you consider using a different type of RI?*
    a. *If you traditionally use accelerator-based light sources, could you consider using a laser-based source, or vice-versa? If yes, which? If no, why not?*
    b. *For your area of research, do you see synergies between the different types of RIs that could be further exploited or further developed? If yes, which?*
    c. *Can you see new research opportunities arising from the combination of offers by different RIs?*
5. *Please provide any further remarks, comments, or recommendations regarding the European landscape of the UV and x-ray sources*

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Annex 2: Feedback from Expert Users on Spreadsheet

Facilities included in the spreadsheet

The European facilities included in the spreadsheet are the most used facilities in Europe by the expert users, with the exception of ANKA, not included in the spreadsheet, mentioned by only one of the users. Outside Europe, the most used facilities by the European expert users are LCLS (USA) and SPring8 (Japan), reflecting the lack of an operational XFEL in Europe. The recent start-up of European XFEL and SwissFEL (which took place directly after EUCALL's data collection) can be expected to fulfill this need. The ALS facility in Berkeley (USA) and APS (Argonne, USA) were mentioned in particular as non-European synchrotron facilities most often used by European scientists.

Availability of RIs in Europe

The expert users are generally satisfied with the instruments and beamlines available at the different RIs in Europe. The planned European XFEL and high-energy lasers at the ESRF are recognised as two experimental capabilities which will keep the European RIs scientific environment as a worldwide leader in science in extreme conditions. Nevertheless, the availability of beamtime and the oversubscription of certain facilities are identified as potential limiting factors for the development of the corresponding scientific activities.

Condition to use a different type of RI

Most of the expert users surveyed reported they commonly use both accelerator-based and laser-based sources for their experiments. If the performances are compatible with the experiments the type of source, meaning the way the radiation is generated, is unimportant. Some users recognize that the visibility of the capabilities of the laser-based sources, out of their specific domain, seems limited and wish for more dissemination and networking about these facilities. There seems to be a specifically low visibility of the ELI facilities' potential and these facilities were only mentioned with some general expectation of available beamlines. In terms of synergies, one user suggested the organization of a Laserlab-Europe-like network involving all the RIs on the EUCALL spreadsheet.

Identified issues and missing elements:

- Optical laser driven light sources with repetition rates >10 kHz and the characteristics (flux, reliability, focus, light) of a typical synchrotron. A great hope is expressed that the Max Borne Institute (MBI) or ELI-ALPS' beamlines will soon come up to their target specifications and offer really reliable, hands off, 90% up time, user modes similar to PETRA III or BESSY 2.

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- A seeded FEL with the parameters and quality of FERMI but at 10 kHz or higher repetition rate would boost the research dramatically. The key issue is routine operation and reproducibility of the parameters.
- RIs strongly focus on UV, X-ray and high-intensity work, however the capabilities for multidimensional vibrational (2DIR), electronic (2DEL) spectroscopy facilities are under presented. Furthermore, multidimensional VUV and x-ray spectroscopies have been shown to be viable methods. There is an emerging and growing need to improve access to facilities which can determine atomic coordinates of chemical, nano- and biochemical systems after optical excitation at fs time resolution.
- Special double pulse schemes introduced at the FELs, especially if the spectral and temporal separation can be somewhat tuned. This is to some extent possible at the LCLS in the soft x-ray domain but also at FERMI, at lower energy.
- The capability to tune the FEL photon energy over a larger range, and for instance pump at one element and probe at another one - this requires at least 100 eV energy difference.
- Attosecond x-ray pulses from FELs, which would enable unique valence dynamics studies.
- There are too few fs sources in the 200-300 nm (4 – 6 eV) region.
- 'True' soft x-ray (1st harmonic covering 250 – 1500 eV) capabilities are limited – the SCS instrument at European XFEL will not cover this need. The soft x-ray beamline (Athos) at SwissFEL is expected to make a big difference, but as SwissFEL runs only at 100 Hz, many spectroscopic techniques will not be exploitable there.
- The capabilities of the experimental end-stations at XFELs are considered by some users to be sparse, while end-stations at HHG sources "essentially do not exist" beyond university scale laboratories via Laserlab Europe, but will become available at the ELI pillars. It is desired to have access to strong magnetic fields, low temperatures, and capabilities related to *in-situ* sample preparation – it is noted that these are not present at LCLS either.
- An interesting opportunity would be to facilitate access to relativistic ultrafast electron diffraction at a light source - there is no user facility so far worldwide but a kind of facility with which one can collaborate at SLAC.
- The availability of intense, ~10 femtosecond x-rays in the soft x-ray range with variable polarization, which is currently only really provided in the USA (LCLS SXR). This will be partly addressed by European XFEL, SwissFEL and FERMI, but it is not at present clear whether the availability of beamtime will be satisfactory.
- The combination of cryogenic environments and a hard x-ray diffractometer is something that is only going to be available at SwissFEL.
- An instrument with capability to do IR-pump soft x-ray-probe with overall temporal resolution of 10 fs (jitter).

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- FEL and laser-driven sources with shot-to-shot stability <1% similar to synchrotrons.
- User friendly, reliable and stable laser-driven sources which can thus run in a real user mode, so far only promised by ELI facility.
- Time-resolved micro- (or nano)-spectroscopy to investigate dynamic processes also in complex materials, where a region of interest has to be prepared/selected.
- High-resolution spectroscopy in the near-infrared (NIR) spectral range (as required e.g. at the PALS facility) to conduct research benefiting from a very narrow line of the gas laser with a fundamental frequency of 1.3 µm.
- Optical spectroscopies, such as Raman and infrared, are mandatory. The outcomes from these techniques importantly help to drive the interpretation of x-ray diffraction (XRD) data. For this reason, it can be recommended that XRD and x-ray scattering (XRS) beamlines could be provided with Raman and IR optical spectroscopy, at least just table-top IR spectroscopy.
- Each synchrotron facility with "high-pressure" beamlines could consider to set-up a top edge Fourier transform infrared (FTIR) beamline with a diffraction-limited beam spot in order to fit small samples in diamond anvil cells. Synergies between this FTIR beamline and the XRD and XRS high-pressure beamlines could then be promoted.
- The facility could significantly support the complex sample preparation procedures for users, both from the technical and economical side, otherwise this type of research could remain rather confined in a small community.
- Very long pulse, high energy drivers for developing warm dense matter in local thermodynamic equilibrium, studying dense plasma flows and turbulence are missing. In this case, optical lasers are not ideal drivers - something more along the lines of the Thor accelerator (able to reach pressures of one million atmospheres) at Sandia (or better) is required.
- A synchrotron-based x-ray diffraction and x-ray imaging capability in connection with a high-energy drive laser is missing in the list, but would be highly beneficial (e.g. proposed as HPLF-II at ESRF).
- A short-pulse betatron emission being used at XFELs, to give them access to EXAFS type spectroscopy, and possibly short pulse laser technology being used to provide x-ray/proton heating/damage etc at beamlines during experiments.

Potential synergies

- Synergies among HHG-driven and free-electron laser driven soft x-ray beamlines. HHG has better spectral stability and automatic synchronization between optical pump and soft x-ray probe pulse, much better longitudinal coherence properties. FELs have larger photon flux and brightness and allow for nonlinear physics experiments to be performed even in the soft x-ray domain.

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- Spectrally-resolved versus time-resolved studies combining experiments at synchrotron radiation facilities and at HHG laser based facilities and FELs: these techniques are very complementary and crucial for a full interpretation of the experiments. The geographical proximity between complementary light sources can be an advantage.
- The possibility to perform relativistic electron scattering using photo-injectors.
- Due to the limitation in availability of state-of-the-art end stations at XFEL and HHG facilities, a suggestion is for dedicated, expensive state-of-the-art instrumentation which could potentially be shared between facilities. Particularly large equipment is not transportable (such as a 7 Tesla superconducting magnet, which is specifically requested), but devices such as a photoelectron spectrometer could easily be moved around.
- The most important synergies to coordinate are between HHG sources and synchrotrons/XFELs. HHG sources can provide extremely short pulses, while FELs give more photons – this contrast is interesting for future experiments.
- Synergies between hard XFELs and XUV sources such as FERMI, as well as between these two and HHG or plasma-based sources of soft and hard x-rays.
- Use of relativistic electron bunches for ultrafast electron diffraction.
- Combination with time-resolved x-ray diffraction and spectroscopy.
- Development of compact (soft) x-ray sources which would allow users to do experiments in the home lab, preparing the high-end experiments at large RIs.
- Non-linear light-matter interaction in the soft x-ray spectral range is an area where capabilities of different RIs overlap and can be used in concert.
- It is recommended that the laser sources at x-ray facilities match the accelerator sources better for instance in terms of pulse length or repetition rate.
- There is some benefit to coordinating better angular resolved photoelectron spectroscopy (ARPES) measurements with other kinds of measurements that measure long-range structural order (e.g. diffraction).
- Sharing codes, targetry, or beam characterization tools could be of use.
- There will be great synergy between HED/HIBEF at European XFEL (short timescales) and HPLF at ESRF (longer timescales) for experiments on matter in extreme conditions. In Europe, European XFEL's HED instrument will cover the activities presently performed at LCLS's MEC.
- A combination of different RIs makes it possible to cover a wider range of irradiation conditions. One RI can be used as a test stand for a particular diagnostic tool or technique which will be utilized within other RIs later on.
- Synergies between x-ray science on large laser platforms (NIF, Omega, LMJ) and that on XFELs. It is doubtful whether the size of laser at NIF/LMJ will ever be available at

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an XFEL - thus combining the ability to obtain the most extreme conditions with a high-quality short-pulse x-ray beam.

- An important part of the case for a UK-XFEL is to site their XFEL beside the CLF, allowing the CLF laser beams to be piped to the UK-XFEL hutches. Combining NIF with LCLS, or European XFEL with CEA's Megajoule Laser facility (LMJ) would undoubtedly have led to new research opportunities. To address this, it would be very beneficial if any future XFELs or large lasers could be sited beside large lasers or an XFEL respectively.
- A combination of XFEL and synchrotron radiation in combination with a high-energy drive laser would be very beneficial (like it is under construction at SACLA/ SPring-8 in Japan).

Recommendations regarding the European landscape of the UV and x-ray sources

- EUCALL activities should be supported after 2018 to continue and enhance the quest for a synergy between different RIs.
- The information included in the Spreadsheet of UV and X-ray beamlines/instrumentation at European Advanced Laser Light Sources could be organized according to type of experiments (such as imaging with its sub-divisions) to see the options in which facilities the experiment could be performed in the most attractive way.
- Efforts to make access/funding easier, to develop more standard schemes, and keep support high could show success. In addition, in order to prepare successful proposals which are awarded beamtime at ALL-RIs, large collaborations are sometimes necessary between users who don't often work together.
- For FEL-based research, especially time-resolved measurements, reliability and excellent support by the facility is a very important aspect as experiments are getting more and more complex. The risk of getting no results during a beamtime is quite high. From experience, this is different compared to experiments at storage ring sources.
- The "low energy" UV to XUV ranges should be actively maintained accessible and further developed, since a number of important challenges in AMO are specific to that domain.
- Covering the range from the deep-UV (typically wavelengths shorter than 300 nm) to the hard x-ray range is necessary.
- One should keep room not only for large-scale experiments with large cooperation groups, but also for smaller, more spontaneous projects, which might be a stimulus for the "big science".

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- A stronger emphasis on overall time resolution, sample environment control (temperature, magnetic fields, pressure), and flexible sample pump schemes for time-resolved experiments is important.
- Europe is at the forefront of extreme conditions research with European XFEL's HED instrument, and ESRF-EBS.
- These sources would benefit from the technological contribution of groups of users. These groups may help develop beamlines, with well targeted aims, as it often happens in neutron scattering large scale facilities. For this purpose, UV and x-ray facilities could provide beamtime for instrument development, which are often lacking.
- A European target network to easily access a variety of different samples would be highly beneficial. Existing plans for that should be further pursued.
- Aim for complementary RIs not competing RIs.

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