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| The Extreme Light Infrastructure Delivery Consortium  ELI ERIC Documents  Final Presentation - September 12, 2019 |
| Annex 1 - Technical and Scientific Description |
|  |
| **Prepared by:** ELI-DC Management for review for submission of the ELI ERIC application to the European Commission. |

**Background**

The following sections define the essential scientific and technical nature of each ELI Facility. The timing of availability for ‘User Access’, and its respective estimated costs of future operation for the first years, up to ‘Steady-State Operations’ is also described. The sections briefly describe the current legal status of each ELI Facility and how that may affect access in the future relative to ELI-ERIC.

**Considerations**

There have not been considerable revisions relative to the previous version of the document, from July 8.

Costing information has been cross-checked with other documents (Annex 2) and updated. Data related to milestones at each facility have been updated relative to previous versions to reflect the most up-to-date information.

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# Purpose and Scope of This Document

This document describes the scientific purpose and technical systems that ELI ERIC will provide to researchers. The specific aspects of the facilities the Host Countries will make available for ELI ERIC are described here. This document is foundational for determining the scope and definition of ‘Operations’ for ELI ERIC .

The document lists the scientific objectives and purpose of ELI ERIC. In some cases where relevant, reference is made to the ELI ‘White Book’, the primary technical ELI document prior to construction. It is recognized that aspects of the vision for ELI described in that important document remain, but the for the purposes of this document and establishment of ELI ERIC, only the technical facilities offered by the founding ERIC Host Members are described.

The current scientific scope is summarised, as are the technical aspects of the ELI Facilities. The budgetary and schedule elements at the start of Operations are also indicated. This information is a reference for the ELI ERIC Statutes, especially Article 17, Commitments and Resources, and is the baseline for agreements between ELI ERIC and facility owners (Host Institutions) to make the ELI Facilities available for the user community. As such, this document is an integral part of the ELI ERIC Statutes at the initial formation of ELI ERIC, and stands as the legal reference relative to the scope and mission of the facilities.

# Introduction and Background

The Extreme Light Infrastructure is an international laser facility with the aim to develop new interdisciplinary research opportunities using extreme light from the most intense lasers in the world dedicated to the puporse of research. These lasers and the secondary radiation derived from them will enable unprecedented discoveries across a broad range of scientific disciplines as well as societally relevant applications. The facilities will be based on two sites, located in the Czech Republic and Hungary. They are being made available to an international scientific user community.

The specific goal of ELI, stated originally in the ELI White Book and still relevant, is to develop a ‘High-Energy Beam Facility, responsible for development and use of ultra-short pulses of high-energy particles and radiation stemming from relativistic and ultra-relativistic interactions’, as well as to address one of the ‘Grand Challenges’ listed in it, specifically in the generation of ‘Ultra-short pulses of energetic particles (>10 GeV) and radiation (up to few MeV) beams produced from compact laser plasma accelerators’.

The ELI Facilities will be the most multifunctional of all existing and planned laser facilities. They are designed not only to serve researchers who specialize in laser science, but they will also accommodate researchers from other fields such as material sciences and engineering, medicine, biology, chemistry, and astrophysics.

With this variety in research activities, they are expected to deliver significant societal benefits and drive innovation in the medium and long term, including improved oncology treatment (ion radiation beams), medical and biomedical imaging, a new generation of photonics and the development of new methods of nuclear waste processing through transmutation.

* **The ELI Attosecond Light Pulse Source (ELI-ALPS)** **in Szeged, Hungary** is establishing a unique facility, which provides light sources between THz (1012 Hz) and x-ray (1018- 1019 Hz) frequency range in the form of ultrashort pulses with high repetition rate. ELI-ALPS will be dedicated to extremely fast dynamics by taking snap-shots in the attosecond scale (a billionth of a billionth of second) of the electron dynamics in atoms, molecules, plasmas and solids. It will also pursue research with ultrahigh intensity lasers.
* **In Dolní Břežany, near Prague, Czech Republic, the ELI-Beamlines** facility will focus on the development of short-pulse secondary sources of radiation and particles, and on their multidisciplinary applications in molecular, biomedical and material sciences, physics of dense plasmas, warm dense matter, laboratory astrophysics. In addition, the facility will utilise its high-power, high-repetition-rate lasers for high-field physics experiments with focused intensities of about 1023 W/cm2, investigating exotic plasma physics, and non-linear QED effects.

The ELI Facilities will be the most multifunctional of all existing and projected laser facilities. With a collection of the most powerful and shortest-pulsed systems in the world, it will also be among the most extreme. More precisely, ELI will be the first infrastructure dedicated to the fundamental study of laser-matter interaction in the ultra-relativistic regime (I > 1024 W/cm2). The facilities are already testing a new generation of innovative, very compact accelerators delivering energetic particle and radiation beams of femtosecond (10-15 s) to attosecond (10−18 s) duration.



*Figure 1 - The Highest focused intensities over time. CPA and solid-state laser technology have pushed the present peak intensity beyond the range of 1022 W/cm2. ELI ERIC will increase that by more than one order of magnitude. Shown also is the SLAC E144 experiment (blue dot) that achieved high intensity by boosting the laser-matter interaction into a relativistic frame. The horizontal lines indicate the intensity of the ponder motive (quiver) energy Up of an electron at 800nm (Ti:Sapphire) laser equal to one atomic unit; and for Up to be equal to Electron rest mass; or the ultimate goal of Schwinger intensity Y=1 where the vacuum becomes unstable and light is converted to matter. Source: P. Bucksbaum, Stanford Univ.*

Originally the ELI ‘White Book’, as presented in 2011, laid out a vision for the facility that will push the limits of ‘extreme light’ and laser technology that is as relevant now as ever:

Today’s top specifications of high power laser systems are characterized by a peak power between one and two petawatts (PW) at very low (sub Hz) repetition rates, this being unchanged over more than one [now two] decade now. The majority of high power systems, however, still rest at the 100TW level. ELI and its national predecessor projects like ILE and Vulcan-10PW will boost the peak power of single lasers (modules) into the 10PW or multi-10PW regime at much higher repetition rates, constituting an evolution of more than one order of magnitude in both of these parameters.

This vision opens the way to even more powerful, combined, coherent 100PW laser systems foreseen to be realized in future ELI ‘pillars’, based on technologies being deployed for the first time at ELI facilities. Such systems open up a new type of interaction, enabling for the first time the possibility to penetrate beyond atomic physics to explore matter strata relevant to nuclear physics, particle high energy physics, astrophysics, fields traditionally studied with high energy particle accelerators. It is expected that ELI may bring a completely new approach to the investigation of fundamental physics. The laser ultra-relativistic intensity is ELI’s essence, leading to the:

* Highest electromagnetic field,
* Possibility for light to move matter, electrons and ions at relativistic velocity,
* Generation of coherent or incoherent high energy radiation, X or γ ,
* Possibility to produce much shorter pulses than currently possible, eventually even shorter than the attosecond range.

These four unique features alone or combined offer a new set of powerful structural dynamic tools.

As the ELI facilities are completing construction and ramping up the laser systems towards their final specifications, the global attention for high power lasers has increased. In 2018 the Nobel Prize for Physics was awarded to Gérard Mourou, and Donna Strickland for their work on Chirped Pulse Amplification (CPA). While scientists eagerly await the unique new capabilities the ELI facilities offer, these opportunities are possible due to Nobel Prize winning work on the underpinning technology.

For ELI, this Nobel Prize is special in many ways. It highlights the very technology that makes extreme lasers possible. Without the invention of CPA by Mourou and Strickland, it would not be possible to amplify the power of a laser pulse to the PW regime operating at ELI facilities. The concentrated power would destroy components and the lasers would literally burn up.

Altogether, the ELI Facilities represent nearly 55.000 sqm on two sites. Together the ELI Facilities are expected to include up to 400 scientists engineers, technicians and support staff.

# The ELI Facilities relative to the Extreme Light Infrastructure ERIC

Access to the ELI Facilities will be competitive, international, and open to users from within and outside the Members countries, based on principles established in the European Union Charter for Access to Research Infrastructures[[1]](#footnote-2). All ‘User Access’ must be subject to peer review. ELI ERIC will ensure a common access point for users responding to a unified call for proposals, including all the available capabilities of the ELI Facilities in an integrated way.

From a scientific perspective, access is ‘open’, meaning that the ELI Facilities are open to potential researchers from Member countries, and also from non-member countries. Proposals are competitive and being ‘open’ also means the data and eventual use of the data in publications shall be available and reviewable to anyone.

In addition to ‘open’ access, there is also be ‘proprietary’ access, which is paid by the user and thus the results in the form of data may be the property of the user and ‘closed’.

There will also be possibilities for access to technology development in terms of collaboration on innovations and procurement. Training and education for capacity is a priority for the Members and the European Research Area, but may also extend beyond the Members.

The Host Members commit to make the ELI facilities available to ELI ERIC. This contribution from the Hosts is in the public interest and the costs of the investment for construction are not amortised or factored into the Operations Costs. The concept of *availiability* does not require, imply, or exclude a *transfer of* *ownership* of the facilities, in part or in full. The meaning of *availability* in this specific context is defined and agreed between ELI ERIC and its Host Members. It is legally regulated through specific agreements on facility operation between the ELI ERIC, the Host Member, and where applicable, the owners of the ELI Facilities.

Those agreements cover their operation, support and management, and will refer directly to the ELI ERIC Statutes to establish their legal basis. They shall take into account pre-existing commitments, liabilities and obligations, incuding those defined in the European Structural and Investment Funds (hereinafter reffered to as ‘ESIF’) executive projects.

The agreements are further discussed in the ELI ERIC Management Operations Model and cover two types of milestones relative to availability:

* Technical milestones – described below, namely specific instrument suites and experimental stations, working and ready for user, recommended by a review panel including independent experts and approved by ELI ERIC GA;
* Organisational Milestones – Organisational milestones are defined independently for each ELI Facility.

This approach must be consistent with the stated goal of the ELI ERIC Statutes to operate as a single legal entity and evolve in a direction similar to other leading research infrastructures, i.e. toward a single integrated organization and management, as defined in Article 2.1 of the ELI ERIC Statutes. The time of the transition depends a range of factors is subject to agreement.

The following sections provide detailed descriptions of each ELI Facility and define the essential scientific and technical nature of each as well. This forms an important basis for the above-described approach to making ELI Facilities available. The timing of availability for ‘User Access’ for each facility, and its respective estimated costs of future operation for the first three years, up to and including the first two years of ‘Steady-State Operations’ is also described. The sections briefly describe the current legal status of each ELI Facility and how that may affect access in the future relative to ELI ERIC .

# ELI Attosecond Light Pulse Source (ELI-ALPS)



***ELI-ALPS Facility in Szeged, Hungary***



The ***ELI Attosecond Light Pulse Source (ELI-ALPS)*** Facility, in Szeged (Hungary) will make available to an international community, within ELI ERIC, a wide range of radiation and particle sources, emitting, in a stable-in-specifications and robust-in-operation manner, energetic pulses of ultrashort duration and coherent radiation in the attosecond (10-18 s) time range. It is a single-site, greenfield facility occupying more than 24.000 sqm, and expected to employ approximately 200 staff.

The ELI-ALPS Facility is currently owned and built by ELI-HU Non-Profit Ltd. (ELI-HU), an independent state-owned, non-profit company that is 90% owned by the Hungarian State, and 10% owned by local stakeholders. ELI-HU has full autonomy and legal personality in Hungary.

# Technical Structure and Sources

The primary mission of the ELI-ALPS Szeged research facility is to make a wide range of ultrashort light sources accessible to the international scientific community user groups.  Laser driven secondary sources emitting coherent extreme-ultraviolet (XUV) and X-ray radiation, that are confined in attosecond pulses is a major research initiative of the infrastructure. A secondary purpose of the facility is to contribute to the necessary scientific and technological developments required for high peak intensity and high average power lasers.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **PRIMARY LASER SOURCES** | | **Peak power** | **Average power** | **Pulse energy** | **Pulse duration** | **Repetition rate** |
| ***ELI-ALPS*** | **HR1** | >0.13 TW  > 0.16 TW | 100 W  80 W | > 1 mJ  > 0.8 mJ | <2.2 cycles  <1.9 cycles | 100 kHz |
| **HR2** | > 1 TW | 500 W | > 5 mJ | < 1.8 cycles  (< 6 fs) | 100 kHz |
| **MIR** | > 3.6 GW | 15 W | > 0.15 mJ | < 4 cycles  (<42 fs) | 100 kHz |
| **MIR HE**  **foreseen upgrade** | ~ 0.5 TW | 15 W | ~ 15 mJ @ 3μm  ~ 20 mJ @ 1.5μm | ~ 3 cycle  (30 fs) | 1 kHz |
| **SYLOS2** | > 5 TW | 35 W | > 35 mJ | < 2.2 cycles  (< 7 fs) | 1 kHz |
| **SYLOS3**  **foreseen upgrade** | ~ 15 TW | 120 W | ~ 120 mJ | ~ 2.5 cycles  (~8fs) | 1 kHz |
| **SYLOS Experiment Alignment** | 3 TW | 0.4 W | > 40 mJ | < 12 fs | 10 Hz |
| **HF PW** | > 2 PW | 340 W | 34 J | 17 fs | 10 Hz |
|  |  |  |  |  |  |
| **THz Pump** | > 1 TW | 25 W | > 500 mJ | 0.5 ps | 50 Hz |

***Table 1 –ELI-ALPS Foreseen Performance Parameters for Laser Sources***

The ELI-ALPS infrastructure provides the users, in the fields of scientific research and industrial applications, primary laser pulses in conjunction with an impressive array of synchronized secondary light and particle pulses. The outstanding characteristics of the source parameters include:

* Few-cycle pulses, from the terahertz/infrared up to the petahertz/ultraviolet, with an impressive 10 Hz to 100 kHz repetition rate
* Attosecond, extreme-ultraviolet, soft and hard x-ray pulses with a 10 Hz - 100 kHz repetition rate and pulse energies ranging from few J to mJ
* Sub-femtosecond hard x-ray pulses up to the keV photon energy range and controlled ultra-relativistic pulse shapes with ultra-high contrast at 1Hz repetition rate.
* Relativistic and ultra-relativistic particle and spatially coherent x-ray sources with femtosecond duration.
* Controlled ultra-relativistic pulse shapes with ultra- high contrast at a few Hz repetition rate

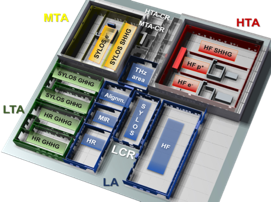
A parallel mission of ELI-ALPS is to contribute, with the other ELI Facilities, to the technological developments towards high peak power and high average power lasers for especially for attoscience and applications. The parallel existence of attosecond pulses and PW-class lasers in the same facility, offers time-resolved investigation possibilities of relativistic light-matter interaction.

The ELI-ALPS facility has a specific focus towards the stimulation, through spill over effects, of industrial applications, taking into account also the possible strong impact on its surrounding territory, which will host a large Science Park.

|  |  |  |
| --- | --- | --- |
| Availability of Laser Sources ELI-ALPS | Commissioning StartS | Access for Users |
| HR1 | 10/2017 | Available (0.8 mJ, <1.9 cylcles)  10/2019 (full specs) |
| HR2 | 8/2019 | 11/2019 |
| MIR | 10/2017 | Available |
| MIR HE – foreseen upgrade | 10/2020 | 01/2022 |
| SYLOS  + foreseen upgrade | 3/2019 | 5/2019 (35mJ)  01/2022 (100 mJ) |
| SYLOS Exp Alignment | 12/2018 | Available |
| HF PW | 5/2018 | 3/2021 |
| HF 100 – POTENTIAL upgrade | 10/2021 | 12/2022 |
| THz Pump | 7/2019 | 6/2020 |

***Table 2 – ELI-ALPS Milestones for Laser Sources***

# Experimental Stations



***Figure 1 – Layout of ELI-ALPS Experimental Stations***

### ELI-ALPS offers a combination of numerous synchronized ultrashort high intensity laser pulses with cutting-edge secondary sources and advancedusers’ end-stations will create an outstanding environment for fundamental and applied scientific research. There are a few areas where ELI-ALPS will from the beginning be world leading:

### Valence and Core Electron Science - Dynamics of valence and core electrons in small systems can be individually monitored and controlled with Attosecond pulse interactions.

### Visualization of ultrafast structural dynamics and correlation effects – Combinations of sources with ultrashort pulses and short wavelengths, allow the visualization of charge dynamics in complex and (strongly) correlated systems.

* Ultrafast surface and condenced mater dynamics - Beyond state of the art high repetition rate attosecond sources in conjunction with a sophisticated NanoEsca users’ end-station open up unique opportunities in surface and condence mater science.
* THz Radiation research - High-intensity, ultrashort THz sources with unprecedented peak electric field strength (up to 5 MV/cm) and 1 mJ pulse energy will be available in the 0.1–2 THz frequency range.

### The unique combination of the high repetition rate radiation sources at ELI covering the electromagnetic spectrum from the X-ray to the far infrared and THz make this facility very attractive for research on complex, applied systems. Applied research areas include new particle sources, nanotechnology, cultural heritage, biological imaging and biomedical applications such as advanced phase-contrast tomography and multidimensional spectroscopy.

|  |  |  |
| --- | --- | --- |
| Secondary sources ELI-ALPS | Commissioning StartS | Access for Users |
| Atto1: GHHG HR1 & 2 Gas (LTA4) | 8/2018 | 12/2019 (HR1)  5/2020 (HR2) |
| Atto2: GHHG HR1 & 2 Condensed (LTA3) | 10/2018 | 2/2020 (HR1)  5/2020 (HR2) |
| Atto3: GHHG SYLOS Compact (LTA2) | 10/2019 | 6/2020 |
| Atto4: GHHG SYLOS Long (LTA1) | 10/2019 | 10/2020 |
| Atto5: SHHG SYLOS (MTA) | 4/2021 | 1/2022 |
| Atto6: SHHG HF (HTA) | 4/2020 | 1/2022 |
| THz1: spectroscopy (THz) | 10/2019 | 1/2020 |
| THz2: high energy (THZ) | 1/2020 | 4/2021 |
| Particle1: electron- SYLOS (MTA) | 6/2020 | 9/2021 |
| Particle2: Electron PW – foreseen upgrade (HTA) | *12/2021* | *1/2022* |
| *Particle3: Ion Beamline – Potential upgrade* | *12/2021* | *1/2022* |

***Table 3 –ELI-ALPS Seondary Sources Milestones***

|  |  |  |
| --- | --- | --- |
| Experimental Stations ELI-ALPS | Commissioning StartS | Access for Users |
| Reaction Microscope | 11/2019 | 9/2020 |
| Amo / VMI | 4/2020 | 12/2021 |
| Condensed Matter | 12/2019. | 5/2020 |
| Nanoscience & Nanofabrication | 6/2018 | 8/2019 |
| MIR ATTO foreseen upgrade | 12/2021 | 01/2022 |
| Semiconductor | 6/2020 | 9/2020 |
| Chemreaction | 6/2020 | 11/2020 |
| Liquid Jet / Ultrafast Bio (Hr, Mir, Thz1) | 9/2020 | 7/2021 |
| Radiobiology / biomedical | 8/2018 | 2/2020 |

***Table 4 –ELI-ALPS Experimental Stations Milestones***

The table above lists the stations expected to come available to ELI ERIC as a part of ‘User Access’ in the coming years. They are the critical technical milestones for ELI-ALPS and Hungary as a host in relation to ELI ERIC . Stations are expected to be available at various different times. Once the final experimental station has been opened for User Access, the facility will be considered to have entered ‘Steady State Operation’ mode. In additional the table above presents foreseen upgrades of the facility that shall be subject of future review and considerations of ELI ERIC.

As primary laser and accelerator sources begin commissioning, early user groups will assist in helping to characterise the sources and finalize construction of the experimental stations. These activities are managed and initiated directly through ELI-ALPS. As the first lasers (MIR, HR1) became operational at the end of 2017, access for assistance in commissioning has already been provided for the first international commissioning user groups (FORTH Greece, ETH Zurich, CEA France, Hebrew University, Freiburg University, Aarhus University) since then.

As each experimental station passes commissioning and comes online, supported by a functioning primary source and/or secondary source, the User Access program can begin and ELI ERIC can begin to accept proposals for those stations.

The confirmation and acceptance of each experimental station will be monitored and a formal ‘Operational Acceptance Review’, consisting of independent experts, experts from ELI-ALPS, and experts from the other ELI Facilities will confirm readiness for Users and make a formal recommendation to the ISTAC to the ELI ERIC General Assembly.

# User Access and Operational Modes

The access mode will be familiar to users of other leading laser and research facilities. Experiments are expected to be conducted in terms of days and in some cases weeks. Overall the facility goal is to be **available [220 days/yr x 8 hrs/day] for a total of 1.760 hrs/Yr**.

# Aspects relative to Operations and the Relationship between ELI ERIC and ELI-ALPS

While ELI ERIC is mandated to manage access to the ELI-ALPS facility as it is made available, the physical plant of the facility is owned and will be managed directly at the beginning by ELI-HU Non-Profit Ltd. (ELI-HU). It is a ‘research organisation’ for the purposes of state-aid for research and development.

In addition to the important technical and scientific milestones listed above, there are also organisational milestones linked to the overall integration of ELI-ALPS into ELI ERIC . Those organisational milestones are listed in the table below.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Integrated Organisation Model ELI-ALPS | 2019 | 2020 | 2021 | 2022 |
| Governance | x | x | x | x |
| Science Policy | x | x | x | x |
| User Access | x | x | x | x |
| Budget | x | x | x | x |
| Employment Policy | - | - | - | x |
| Technology Management | - | - | - | x |
| Facilities Management | - | - | - | x |
| Legal & Liability | - | - | x | x |
| Administrative | - | - | x | x |

***Table 5 – ELI-ALPS Estimated Organisational Transition Milestones***

In the case of ELI-ALPS, activities will transition to ELI ERIC over a five year period with some activities transitioning at the end of the period. Taken together with the technical milestones listed for the Experimental Stations, the overall transition plan can be determined.

The table below lists the estimated costs, relative to User Access, at ELI-ALPS to operate the facility for ELI ERIC from the period 2019-2023, the Transition Period. This is the period of time when it is assumed responsibilities, resources, and assets will undergo a change in management responsibility from ELI-HU to ELI ERIC .

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **ELI-ALPS** | **2019** | **2020** | **2021** | **2022** | **2023** |
| Personnel direct costs | 411 | 1.529 | 2.752 | 3.334 | 3.596 |
| Hardware direct costs | 47 | 1.707 | 4.035 | 4.435 | 5.148 |
| Total Personnel + HW costs | 458 | 3.237 | 6.787 | 7.769 | 8.744 |
| *% of max Personnel and HW* | *5%* | *37%* | *78%* | *89%* | *100%* |
| Other costs | 8.723 | 10.811 | 11.101 | 11.514 | 12.139 |
| Adjusted Other costs | 457 | 4.002 | 8.616 | 10.230 | 12.139 |
| **Total costs** | **915** | **7.238** | **15.404** | **17.998** | **20.883** |

***Table 6 – ELI-ALPS Estimated Access Costs***

# ELI Beamlines (ELI-BL)



***ELI-BL Facility in Dolní Břežany, Czech Republic***



The ***ELI-Beamlines******(ELI-BL)*** Facility in Dolní Břežany, near Prague (Czech Republic), even in its name, underlines its capability to support multiple, different experiments for a range of Users, offering the availability of various laser lines. It is designed to offer a high-energy and high repetition-rate capabilities. It is a single-site, greenfield facility occupying more than 30.000 sqm, and expected to employ approximately 200 user support staff.

The facility is owned and managed by the Institute of Physics of the Czech Academy of Sciences, which has full autonomy and legal personality in the Czech Republic as a public research institution.

# Technical Structure and Sources

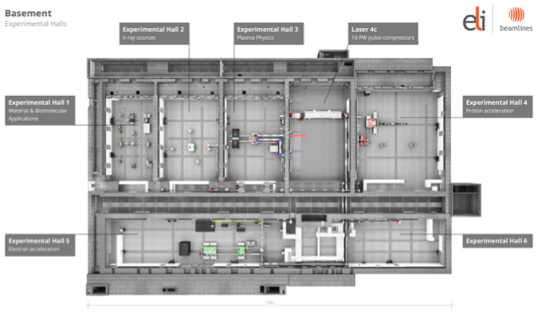
|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **PRIMARY LASER SOURCES** | | **Peak power** | **Energy in pulse** | **Pulse duration** | **Repetition rate** |
| ***ELI-BL*** | **L1** | >5 TW | 100 mJ | < 20 fs | 1 kHz |
| **L2 OPCPA, Dual color** | 100 TW | ≥3J OPCPA /1mJ MIR | ≤ 20 fs | 20 Hz |
| **L3** | ≥ PW | ≥ 30 J | ≤ 30 fs | 10 Hz |
| **L4f** | 10 PW | ≥ 1.5 kJ | ≤ 150 fs | 1 shot per min |
| **L4n** |  | ≥ 1.5 kJ | ns | 1 shot per min |
| **L4p** | ≤1 PW | 150 J | 150 fs-150 ps | 1 shot per min |
| **Astrella** |  | 6 & 10mJ | 20 fs | 1 kHz |
| **Bio-laser** |  | 6 mJ CEP stabilization | 20 fs | 1 kHz |

***Table 7 –ELI-BL Performance Parameters for Laser Sources***

|  |  |  |
| --- | --- | --- |
| Laser Sources ELI-BL | Commissioning Started | Access for Users |
| L1 | 1/2018 | 1/2019 (30mJ)  9/2019 (50mJ)  3/2020 (100 mJ) |
| L2 | 6/2020 | 12/2020 |
| L3 | 11/2017 | 7/2018 (0.4 PW)  12/2019 (1 PW) |
| L4f | 9/2018 | 6/2020 |
| L4n | 9/2018 | 3/2020 |
| L4p | 6/2020 | 12/2020 |
| Astrella | 2/2018 | 4/2018 |
| Bio-laser  ***Table 8 –ELI-BL Beamlines Milestone Dates for Access*** | 4/2018 | 6/2018 |

Furthermore, there is a very strong emphasis on possible applications in different fields of societal relevance like for instance medicine or biology. ELI-BL, together with the connected HiLASE Centre (also owned and managed by the Institute of Physics of the Czech Academy of Sciences) dedicated to the laser technology development and transfer, which already serves as an attractor for companies and spin-offs in different fields installed in the so-called STAR region (Science and Technology Advanced Region) which is surrounding the ELI-BL facility, creates the favourable environment for intensive cooperation between research and industry.

# Experimental Stations



***Figure 3 – Layout of ELI-BL Experimental Stations***

The ultrashort and ultra-intense pulses of light and the particles generated ELI-BL from interaction with solid state and gas target materials will allow a broad spectrum of projects in fundamental and applied research in chemistry, biology, medical technologies, development of new materials, and other areas. The research activities within the ELI-BL project are structured into six experimental halls.

|  |  |  |  |
| --- | --- | --- | --- |
| Secondary Sources ELI-BL | Source | Commissioning Started | Access for Users |
| E1: X-Ray Sources | HHG | 2/2018 | 1/2019 |
| E1: X-Ray Sources | PXS | 3/2018 | 4/2019 |
| *E2: X-Ray Sources* | *Betatron* | *6/2019* | *11/2019* |
| *E2: X-Ray Sources – funded upgrade* | *Compton* | *1/2020* | *12/2020* |
| E5: Laser Undulator X-Ray Sources | LUIS | 3/2019 | 6/2020 |
| E4: Ion Acceleration | ELIMAIA | 11/2018 | 10/2019 |
| E5: Electron Accelaration | HELL | 1/2019 | 3/2020 |

***Table 9 –ELI-BL Secondary Sources/Beamlines and Milestones***

|  |  |  |  |
| --- | --- | --- | --- |
| Experimental Stations ELI-BL | Station | Commissioning Started | Access for Users |
| E1: Material and Biomolecular Applications | MAC | 4/2018 | 1/2019 |
| E1: Material and Biomolecular Applications | Trex | 6/2018 | 5/2019 |
| E1: Material and Biomolecular Applications | SRS | 6/2018 | 3/2019 |
| E1: Material and Biomolecular Applications | ELIps | 9/2018 | 3/2019 |
| E2: X-Ray Sources – *funded upgrade* | Compton Station | 7/2020 | 12/2020 |
| E5: Laser Undulator X-Ray Sources | LUIS Station | 3/2019 | 6/2020 |
| E3: Plasma Physics Platform | P3 | 9/2018 | 10/2019 |
| E4: Ion Acceleration | ELIMED | 11/2018 | 11/2019 |
| E5: Electron Acceleration | HELL Station | 1/2019 | 3/2020 |

***Table 10 –ELI-BL Experimental Stations and Milestones***

Experimental hall **E1** hosts laser-driven secondary sources and experimental end-stations for applications in molecular, bio-medical, and materials sciences. Experiments will exploit synchronized laser photon beams in the VUV and hard X-ray range (High Harmonics Source - A kHz source of ultra-short EUV pulses emitted in a coherent beam with low-divergence and Plasma X-ray Source - femtosecond pulses of X-ray radiation in the spectral range of 4–30 keV).

Instruments include:

* MAC: a Multi-purpose chamber for Atomic, molecular, and optical sciences and Coherent Diffractive Imaging.
* ELIps: VUV ellipsometer for sub-ps experiments; an end-station for VUV and soft X-ray materials.
* Hard X-ray end-station: A modular station for Time Resolved Experiments such as scattering, diffraction, spectroscopy and imaging with X-rays.
* Optical probes and pump beams: An advanced station for optical spectroscopy, including stimulated Raman scattering; the source for a wide array of synchronized pump beams from UV to IR and THz.

The experimental hall **E2** is dedicated to ultrafast and bright, hard X-ray beams. A PW-class laser will be available at a 10 Hz repetition rate. A range of parameters may be adjusted including laser intensity, laser spot size and duration, and electron density in the gas. Electrons are accelerated to relativistic energies and wiggled by the plasma itself (Betatron source) or by a second laser pulse (Compton source). Intense femtosecond X-ray or gamma-ray beams are emitted by a micron-size source. Users may request narrow spectrum (10% energy spread) or broadband radiation in a spectral range from keV to a few MeVs.

The plasma physics platform located in the experimental hall **E3** is a multi-functional experimental infrastructure designed to perform laser-plasma and laser-matter interaction research predominantly on the following topics:

* High energy density physics (HEDP)
* Warm dense matter (WDM)
* Plasma optics (PO)
* Laboratory astrophysics (LA)
* Ultra-high intensity interaction (UHI).

The **E4** experimental area allows users to test various samples with laser accelerated ion sources because of its ion beam transport and dosimetry section, as well as to investigate innovative schemes for laser-driven ion acceleration that can be accommodated in the flexible interaction chamber. The ELIMAIA beamline will allow user to investigate multidisciplinary applications using laser driven ion beams, such as in-vitro radiation biology and pre-clinical studies within the ELIMED international cooperation.

The **E5** experimental hall contains the LUIS beamline and is dedicated to users interested in the irradiation of various samples through the most advanced techniques. It also houses the HELL platform, a flexible experimental area dedicated to users who want to test innovative concepts and use the most advanced technologies for accelerating electrons with lasers at multi-GeV levels.

Apart from the original scope fo the ELI-BL Facility, the table above presents in addition already funded capacity enhancements and upgrades of the facility though dedicated projects ADONIS, HIFI and ELIBIO that shall be subject of future review and considerations of ELI ERIC.

The confirmation and acceptance of each experimental station will be monitored and a formal ‘Operational Acceptance Review’, consisting of independent experts, experts from ELI-BL, and experts from the other ELI Facilities will confirm readiness for users and make a formal recommendation to the ISTAC and to the ELI ERIC GA.

# User Access and Operational Modes

The access mode will be familiar to users of other leading laser and research facilities. Experiments are expected to be conducted in terms of days, and in some cases weeks. Overall the facility has a goal to be **available [220 days/yr x 8 hrs/day] for a total of 1.760 hrs/Year.**

# Aspects Relative to Operations and the Relationship between ELI ERIC and ELI-BL

While ELI ERIC is mandated to manage access to the ELI-BL facility as it is made available, the physical plant of the facility is owned and will be managed directly at the beginning by the Institute of Physics of the Czech Academy of Sciences, which has full autonomy and legal personality in the Czech Republic. It is a ‘research organisation’ for the purposes of state-aid for research and development.

In addition to the important technical and scientific milestones listed above, there are also organisational milestones linked to the overall integration of ELI-BL into ELI ERIC . Those organisational milestones are listed in the table below and detailed in Appendix 1, ‘The Management Operations Model’.

|  |  |  |  |
| --- | --- | --- | --- |
| Integrated Model ELI-BL | 2019 | 2020 | 2021 |
| Governance | x | x | x |
| Science Policy | x | x | x |
| User Access | x | x | x |
| Budget | x | x | x |
| Employment Policy | - | x | x |
| Technology Management | - | x | x |
| Site Management | - | x | x |
| Legal & Liability | - | x | x |
| Administrative | - | x | x |

***Table 11 –ELI-BL Estimated Organisational Transition Milestones***

The Czech Republic commits to make available full capacity of the ELI-BL facilities to ELI ERIC. The costs of the investment into construction are not factored into the Operations Costs.

The table below lists the estimated costs at ELI-BL to operate the facility relative to User Access for ELI ERIC from the period 2019-2021, or the ‘Transition Period’. This is the period of time when it is assumed responsibilities, resources, and assets will undergo a change in management responsibility from the Institute of Physics of the Czech Academy of Sciences to ELI ERIC .

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **ELI-BL** | **2019** | **2020** | **2021** | **2022** | **2023** |
| Personnel direct costs | 2.361 | 4.366 | 6.036 | 6.036 | 6.036 |
| Hardware direct costs | 3.483 | 6.273 | 7.388 | 7.388 | 7.388 |
| Total Personnel + HW costs | 5.843 | 10.639 | 13.424 | 13.424 | 13.424 |
| *% of max Personnel and HW* | *44%* | *79%* | *100%* | *100%* | *100%* |
| Other costs | 10.215 | 10.531 | 10.999 | 11.074 | 11.146 |
| Adjusted Other costs | 4.447 | 8.346 | 10.999 | 11.074 | 11.146 |
| **Total costs** | **10.290** | **18.984** | **24.422** | **24.497** | **24.570** |

***Table 12 – ELI-Beamlines Estimated Access Costs***

1. **Estimated Costs**

To define the conditions needed to reach long-term sustainability, the costs and the possible financial sources need to be detailed. As provided for in the ELI ERIC Statutes, the general principles for the use of the ELI Facilities shall be documented in a stand-alone policy agreed by the GA, and the apportionment of Members’ contributions to the operating costs is laid down in Annex 2, creating also the prerequisites to avoid a significant and lasting imbalance between the use and the contributions by the scientific community of each Member.

In what follows, the basic elements to define costs are presented and can be grouped into the following categories:

1. Construction – Capital investment expenditures (CAPEX) before operations;
2. Operations – Operational expenditures (OPEX) of peer reviewed access;
3. Future upgrades – New investments (CAPEX) needed to improve specifications and available instruments in response to competition and users’ requirements.

The following text focuses on aspects of points 1 (Construction) and 2 (Operations).

# Construction

The total investment (construction costs) of the ELI Facilities will be of around €509,3 million over the construction period as detailed in Table 2.

|  |  |  |  |
| --- | --- | --- | --- |
| Item | ELI BL | ELI ALPS | ELI |
| Building + Land | € 94.643 | € 88.705 | €183.348 |
| Technology | € 181.876 | € 105.435 | €287.311 |
| Services | € 7.601 | € 9.788 | €17.389 |
| Personnel | € 41.206 | € 27.484 | €68.690 |
| Total  ***Table 13 – Construction Costs of the ELI Facilities*** | € 325.326 | € 231.412 | €556.738 |

These costs are completely covered by the Host Countries, through ESIF and national funding, based on the projects, which were approved and monitored by the national Managing Authorities. The investments have been of about 25% in buildings, 65% in technology and 10% in personnel and services. These costs are, from the position of ELI ERIC, non-recoverable and will not be factored into the operating costs of ELI ERIC. No initial investment or construction costs will be paid for by contributions, which are reserved for Initial Operations, Steady State Operations and Upgrades only.

# Operations

The commitment of the Host Members enables other non-Host Members to define a gradual approach to their future commitments and reach longer-term sustainability of the ELI ERIC based on Members´ contributions from 2019 onwards.



***Table 14 – Estimated ELI ERIC Operation Costs for the ELI Facilities***

The entry of non-Host Members during the Initial Operations Period allows for a gradual ramp-up of contributions after the establishment of ELI ERIC, and for a decision on the final level and commitments for their contribution soon after establishment. The early entry allows prospective Members to be involved in setting up the basic rules for the operation of the ELI Facilities, while ramping-up financial commitments at the beginning.

Above are the projected ELI Operating costs, adjusted for current milestones. They probably represent an upper estimate relative to User Access costs during the Initial Operations Period depending on whether or not milestones are achieved. Estimates for must be established and monitored on a yearly basis for the duration of the Initial Operations Period.

# Future Upgrades

The ELI Operating costs do not take into account future upgrades of the laser systems and facilities. They cover the running costs, incuding spares and maintenance.

Advanced laser systems are developing quickly and it is generally recognised that ongoing development will be necessary to maintain competitiveness. To that end specific upgrades projects will be proposed by ELI ERIC management and a 5-year and 10-year analysis will be conducted to understand the potential developments and their costs. Specific upgrade capaigns will be organised to address the capital investment requirements and sources.

# Development and Objectives

The Extreme Light Infrastructure is an important development, not only for the laser community in Europe, but also for the broader European research area. Laser technology is both established and at the same time a fast developing field. As it develops, the field is becoming more relevant for scientific applications, and is already extremely important in terms of European competitiveness.

ELI will have broad benefits for society in areas such as improved clinical cancer therapy, biomedical imaging, and nuclear materials and waste processing. Furthermore, ELI will aid the European photonics industry and will provide educational and training opportunities for new scientists and engineers in photonics and laser-enabled areas of research.

It is not an exaggeration to say ELI ERIC is essential for Europe-wide intiatives to maintain competitiveness in the very strategic field of high-power, short-pulse laser systems and the constituent scientific and innovation fields. The steep development curve of laser technologies indicates the field is well positioned to dramatically disrupt existing large-scale scientific and industrial platforms in the mid and long-term future. Before that can happen, ELI ERIC must demonstrate the capability to operate

# Development of Laser Science and Technology

Europe has taken the lead from Asia and North America in terms of high-power laser facilities and research centres. It is clear that significant concentration occurs in Europe, owing principally to the self-organization of the various institutes and countries involved via European Union programs that have supported and brought a strategic aspect to the field over several decades.

The scientific success and enthusiasm in the field of high-power laser systems has led to an increase in European installations over the past decade. While there are a number of factors driving this development, it clearly parallels the increase in national laser laboratories within the EC-funded European network LaserLab Europe ([www.laserlab-europe.net](http://www.laserlab-europe.net)). According to the website, ‘…the Consortium now brings together 33 leading organisations in laser-based inter-disciplinary research from 16 countries.’ Of those, 22 of the facilities offer access to their labs for research in Europe and beyond.



***Figure 4 -*** *2016 world map by the International Committee for Ultra-Intense Lasers (ICUIL) showing the global extent of PW-class laser facilities. SOURCE: Dr. C. P. J. (Chris) Barty, Lawrence-Livermore National Laboratory.*

The early success of LaserLab Europe provides a foundation for ELI ERIC to continue to build the European laser community. Equally as important, ELI will enable new capabilities and draw attention from other scientific discipline. Based on the success of national laser-based laboratories, the expertise, knowledge and proofs-of-concept for ELI were developed. A community of users has grown up and significant investment has taken place, also supporting the development of European companies to build ELI and other PW class facilities. Continued cooperation in the community is critical for Europe’s continued competitiveness and leadership in this field.

With the discovery of chirped pulse amplification (CPA) and later optical parametric CPA (OPCPA) on ELI systems, there is a jump in laser pulse peak power by 6–8 orders of magnitude, 4 orders of magnitude above the level where the electron quiver energy equals the rest mass energy (or 1018 W/cm2 of the electron). This heralds the relativistic laser plasma interaction and the subatomic regime, including nuclear and particle physics. Future developments at ELI may realistically compete with the world’s most powerful accelerators at a fraction of the cost.

In terms of technology development, ELI ERIC will focus heavily on critical areas of collaboration identified by ELI and leading partners in LaserLab. Key bottlenecks to the reliable and cost-efficient operation of PW-class systems and facilities will be addressed with industry to overcome those bottlenecks. This will not only positively affect European industry in the field, the European Research Area, and the network of partners in LaserLab today, it will directly lead to the sustainable operations of the ELI facilities, ensuring world-class reliability.

***FIGURE 5*** *- Number of petawatt-class laser systems coming online each year, sorted by the continent in which those systems are based. This chart includes operational and under construction facilities.*

*SOURCE: J. Collier, Rutherford Central Laser Facility.*

The physics is clear, and the challenge is to develop the technology. A number of enabling technologies will be developed by ELI, in collaboration with industry and other leading research centers, especially next-generation optical components.

# ELI ERIC Organisational Objectives

# Establish Operation

The combined resources and attention on ELI ERIC will have a profound and long-term impact on science in the field as well technological advancement. But the first objective is pragmatic and localised: to simultaneously stand up and merge the management of two facilities and to efficiently integrate resources.

While there are other multi-site scientific organisations, there are very few greenfield European projects built in different countries using structural funds for the purpose of coming together as one research infrastructure. Also, there are no large laser-based user facilities. ELI will need transition those facilities first into operations before addressing broader interests. This is a technical as well as managerial challenge.

# Establish Collaboration

The second objective is to identify opportunities for technical synergies across of the Europe’s leading high-power, short-pulse laser centres. Historically high-powered, PW-class lasers have been challenging to operate in a user environment, with issues related to reliability and expensive component replacement. Combined, the ELI facilities alone will have more than 30 PW of power.

With partners at national facilities in France, Germany, Spain, the UK, and Italy (all Laserlab Europe Members) ELI will bring together the largest concentration of the most advanced high-power, short-pulse laser facilities in history. There is no real comparison as the ambition is to create an unprecedented collaboration to identify components and processes inhibiting the operation of PW-class lasers, and identify solutions and standard approaches to operations.

It is anticipated that by working together, and together with industry, facilities can lower operations cost by up to 30% in some cases, and increase availability for users up to 90% of beam time. This offers the opportunity to realise unique economies of scale and scope, enabling significant technological advances in a short time period. Such advances will resonate globally throughout the laser industry.

# Establish Reputation

The third ambition is to scientifically demonstrate the performance and potential of the ELI systems early in the operations phase of the scientific program. The ELI facilities, assisted by the experience of other partner facilities will attempt to have 80% of its estimated facility user hours available by 2021, with 90% of its primary laser systems in operations, most of which are high to medium repetition rate.

By comparison, the state of the art today for PW-class lasers is several shots an hour and ELI and some partner facilities will aim to operating at Hz and multi-Hz rates. This is all the more remarkable considering that ELI is operating in some cases world-leading lasers in terms of performance. Early calls will enable experiments at these enhanced repetition rates with joint developments and production of targets for users.

These experiments will not only lead to breakthrough discoveries, but will also enable world record performance for secondary sources, such as GeV wake field acceleration. Such ground-breaking, controlled experiments, early in the ife of the facilities, combined with extensive outreach and dissemination activities, will generate intense interest in ELI and in laser science in general. This will impact the whole of laser science in Europe and the world, leading to many practical applications such as advanced cancer therapies and transformation of dangerous nuclear waste. The ambition is to demonstrate this potential and create a growing, sustainable basis for support for ELI and all laser science in Europe.

# Establish Innovation

The impact of ELI on the innovation and technology of the laser industry won’t stop at the end of the construction stage. The present challenge for the operational stage is a sustainable technological development. ELI will build long-term relations with industrial partners to address problems of procurements of key components and of continuous technological development with a focus on the sustainability of the operations.

In term of relations with the industry, one of the challenges will be to open dialogue with the suppliers to identify the constraints of product improvements or risk mitigation processes (large availability of spare parts, multiples suppliers…), especially in the perspective of a sustainable operation of the ELI facilities on the long term.

The technological development driven by the ELI’s requirements will continue during the operational stage. A few examples are:

* **Key optical components for the high power/high repetition rate lasers.**The transport and focusing optics, as well as the diffraction gratings and the active materials need to be developed further to withstand for a long period of time high energy and high peak power pulses, and over large beam diameters, and this must be done for a high number of shots.
* **Short pulses, large beams metrology.**Disruptive solutions to measure the performances of the systems on short pulses and large beams are necessary, to support the understanding of the unique scientific results that will be achievable with the ELI facilities.
* **Complete control for complex systems.**The experimental systems must guarantee the performances and the smooth operation. Intelligent and completely interfaced control systems are needed.

ELI facilities will focus the collaborations with industrial partners able to disrupt the present technology with innovative solutions. The innovation content won’t focus only on the short term technical aspect but will also address the issues of the sustainability of the solution on the long term, to guarantee to ELI the best performances, the longest uptime and the most efficient control of the maintenance costs. The unique scientific results of ELI will be based, o the long term, on the most sustainable technological solutions of the high peak power lasers.

# Impact in the Host Countries

A key reason for investing in and siting ELI in central European countries is to impact the regions with a high-value research and technology centre. There are multiple studies of other RIs indicating that significant portions of the investment and innovation impact take place within 100km of the facility, showing that proximity matters. Some expected impacts include:

* ***Direct impact from investment –*** The hosts are expected to receive 50-80% of the operating costs from other members, meaning that investment should have a direct impact on the local economy. ELI will track and report on those impacts. It is expected that anywhere from >50% of that will be spent within the local region, affecting two different central European areas.
* ***Increased opportunities for national/local researchers –*** The ELI facilities are all located in cities (Prague, Szeged) with universities. Each university, aware of the upcoming developments at ELI has positioned students and academics with programs to take advantage of the proximity. In this context of this project there are specific activities aimed at reaching local researchers. It is expected that within 5-10 years each country will have leading researchers in the field.
* **Increased innovation opportunities for local** **industry** – Beyond the direct investment impacts described above, the proximity to the facilities will drive innovation in at least two measurable ways. First, capable industry will see an opportunity and approach the facility proactively either to sell products or try to understand how to adapt their offer to the facility. Through ‘Outreach to Industry’ events, both the procurement teams and the Industrial Liaison Officers will help facilitate information sharing about the facilities. In addition, there are some areas where having a local supplier may be advantageous to the facilities for strategic reasons. This may be driven by the low cost of the area, but more likely by the proximity and convenient access to suppliers to adapt technical solutions.

# Key Risks

# Risk Analysis

***Table 15 – High-level Risk Assessment to implementation of the ELI ERIC Facilities***

|  |  |  |  |
| --- | --- | --- | --- |
| **Potential Risk** | **Probability**  *Low 1–5 High* | **Impact**  Low 1–5 High | **Prevention/ Mitigation** |
| **Attracting Staff and Competitive Remuneration –** *There is a risk ELI ERIC will find it difficult to attract ‘world leading’ experts to join the staf.* | 4 | 5 | Active recruitment, term contracts, research opportunities, ‘quality of life’ initiatives |
| **Technical risk of not meeting key parameters –** *Risk that ELI will not achieve some key performance parameters which may prevent some experimental possibilities.* | 3 | 3 | Planning and dialogue with User Community and ISTAC to manage expectations and determine alternative experimental priorities. |
| **Escalation of Salaries over first 5 years –***salaries at ELI ERIC will increase significantly, anywhere from 5-10% annually due to local labour market dynamics*. | 5 | 3 | Planning and dialogue with staff establishing expectations |
| **Equipment/component Obsolescence -** *The technology in the laser systems will develop quickly in the coming year and ELI risks not being competitive if there is not ongoing capital expenditure.* | 3 | 4 | Planning in the form of Technology Roadmap; seeking complementary funding |
| **Bad Initial User Experiences -** *Damage at the beginning due to a) facility not performing b) staff not supporting or c) bad communication/expectation management. This can cause bad word of mouth among researchers and a very slow uptake of services.* | 3-4 | 4-5 | Work closely at the beginning with ‘friendly users’, user surveys, plan for ‘User Coordinators’ to offer ‘concierge’ services |
| **Failure to Successfully Integrate the ELI Facilities –** *Due to management/governance issues the organisational merging is delayed or fails. This leads to increased costs, damage to the integrity and reputation of ELI-ERIC.* | 2 | 5 | Close management monitoring, high-level supported ‘change management’ and training workshops, dedicated resources and reasonable timing expectations |

1. https://ec.europa.eu/research/infrastructures/pdf/2016\_charterforaccessto-ris.pdf [↑](#footnote-ref-2)