Scientific proposal for Enabling Research project

(max 10 pages, excluding title page)

Title	**Conceptual design for a European High Power Laser Fusion Research Facility (HiPER+RF)**
Topic Area	**Inertial Fusion Energy**
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Beneficiary	***CEA***

Abstract

The HiPER+RF project proposes the conceptual design of a next-generation European laser fusion research facility for Direct Drive (DD) inertial confinement fusion (ICF). While Europe leads in magnetic confinement fusion, it lacks a civilian-accessible laser-driven program, leaving a strategic gap with the US and China. Recent ignition breakthroughs at the US National Ignition Facility (NIF) confirm the credibility of ICF and highlight the urgency for Europe to invest in DD as a complementary path to Inertial Fusion Energy (IFE). The facility will be designed to achieve ignition, scale to high gain ($Q \geq 100$), and operate at Hz repetition rates under reactor-relevant conditions. It will integrate diode-pumped solid-state lasers, scalable target fabrication and injection, radiation-hardened diagnostics, and materials capable of withstanding extreme thermal and neutron loads.

The project builds on the HiPER project (2008–2013), Enabling Research on DD and shock ignition (2017–2025), the HiPER+ Roadmap (HPLSE, 2023), and the LaserFusion Erasmus+ project (2024–present). It will unite European civilian IFE community and foster collaboration with industrial partners and start-ups (Thales, Amplitude, Marvel, GenF, Focused Energy, …) and with leading European laser facilities (LULI, PHELIX, PALS, ELI, XFEL). It will address bottlenecks in hydrodynamic stability, laser–plasma interaction, target physics, diagnostics, and materials through advanced simulations and tailored experiments, supplemented by large-scale campaigns at NIF, Omega, and LMJ when required. Seven coordinated work packages cover implosion design, experimental validation, efficient laser drivers, targets and materials, diagnostics, system integration, and community building. The expected output is one general conceptual design, including validated DD target designs, a roadmap for high-repetition lasers with >10% wall-plug efficiency, conceptual designs for reliable target production and reactor-scale diagnostics, and a complete facility layout with safety and licensing specifications.

Beyond technical progress, HiPER+RF will reinforce the European IFE ecosystem through workshops, schools, and industry–academia forums, while preparing long-term EU and national support for ESFRI integration. It will also train the next generation of fusion scientists and engineers. The project offers both a pathway to ignition and high-gain DD fusion and a strategic investment in Europe's energy autonomy, technological leadership, and the green transition.

Introduction.

Climate change and geopolitical tensions make the development of secure, climate-neutral, and affordable energy sources a global priority. Nuclear fusion has long been recognized as a transformative solution. Recent progress at the US National Ignition Facility (NIF), which has repeatedly demonstrated energy (Q > 1, now exceeding 4 with a roadmap toward 10) [1], has renewed worldwide interest in inertial fusion energy (IFE) [2,3]. For the first time, laser-driven inertial confinement fusion (ICF) has provided proof that ignition and net energy gain are possible.
Europe, however, risks losing competitiveness in this strategic field, where the USA and China are investing heavily. To remain competitive, Europe must strengthen its research base and establish a dedicated IFE facility. Without decisive action, Europe could miss the opportunity to lead in this rapidly evolving, high-value domain.

Most large infrastructures (NIF in the US, LMJ in France) rely on the "indirect drive" (ID) scheme, initially developed for stockpile stewardship. While effective for ignition, ID is inefficient for power generation and restricts academic access. By contrast, the "direct drive" (DD) approach irradiates the fuel capsule directly, increasing efficiency by up to a factor of five and avoiding defense-related constraints. DD is therefore the most promising route to civilian electricity generation from laser fusion.

The HiPER+RF project unites the European civilian IFE community, building on the legacy of HiPER (2008–2013), subsequent Enabling Research programs on IFE and direct-drive (2017–2025), and the 2023 HiPER+ Roadmap [4]. It addresses the scientific, technical, and infrastructural bottlenecks to a DD-based ignition facility, engaging leading European institutions and providing an open, civilian-access platform for research and industry. Partnerships will be strengthened with European world-leading laser companies (Thales, Amplitude, Trumpf, …), IFE start-ups (Marvel, GenF, Focused Energy, …), and with colleagues in the US, UK, Japan, and China.

HiPER+RF will establish the foundation for a world-leading European IFE program with large societal impact [5,6,7]. It will drive cutting-edge high-energy-density physics, train the next generation of scientists, and promote industrial innovation in advanced materials, aerospace, and beyond. Most importantly, it will address the critical bottlenecks of IFE and prepare Europe to pioneer clean, secure, large-scale fusion energy production. Moving toward DD opens new opportunities for high energy gain, but also new challenges [8]. These include:

- **STC1** – achieving ignition in DD at high repetition rates
- **STC2** – improving efficiency and energy recovery
- **STC3** – developing reactor-relevant technologies such as robust lasers, advanced targets, new materials, and diagnostics for extreme environments.

Meeting these challenges requires a dedicated research infrastructure, with long-term continuity and critical mass, open to both academia and industry. In parallel, the project will reinforce the European IFE community and conduct tailored experiments on major facilities (ELI, Phelix, LULI, PALS, …) to refine target designs. Strong collaboration is foreseen with the three ELI pillars (which recently launched a programmatic call in IFE), the Helmholtz-Zentrum Dresden-Rossendorf, and the European XFEL. Ultimately, full-scale experiments will be pursued at NIF and Omega in the US and at LMJ in France. Synergies will also be explored with the magnetic confinement fusion community, particularly in materials research, tritium breeding, and diagnostics, as well as in regulatory frameworks, public awareness and partnership with industry

Objectives and expected outcomes.

The overall objective of the HiPER+RF project is to deliver the conceptual design of a European laser-fusion facility dedicated to ignition experiments using the Direct Drive (DD) approach and ultimately demonstrate nuclear fusion in the high gain regime [8-11]. Following the facility conceptual design (and

actually already during the realization of the ENR project), we will work to place the foundations for ESFRI integration of the facility, and for its support from EU as well as from national governments.
The proposed facility will serve as the cornerstone of a future Inertial Fusion Energy (IFE) program in Europe, engaging leading European institutions and establishing an open-access, fully civilian platform for researchers and industry. It will enable the transition from proof-of-principle experiments to scalable fusion energy production.

The project's major goals are structured into four General Objectives (GO)

GO1: Develop conceptual design for DD-based IFE facility.
This will include the definition of target configurations for direct drive schemes, with emphasis on shock ignition but being open to other DD schemes, capable of achieving ignition with moderate energy gain ($Q \geq 2$) and progressing towards high-gain conditions ($Q \geq 100$), alongside the validation of models describing hydrodynamic and parametric instabilities.

GO2: Address reactor environment challenges (targets, materials, diagnostics).
This will deal with robust materials for the first wall and blanket solutions under extreme radiation loads, develop scalable and cost-effective target fabrication and injection systems, and create advanced diagnostics for real-time monitoring of implosions and laser–plasma interactions.

GO3: Roadmap for efficient, high-repetition rate (HRR) laser systems.
Here we will identify cost-effective laser architectures capable of broadband operation, with wall-plug efficiencies above 10%, that is approximately 2 orders of magnitude better than NIF/LMJ lasers. We will address the technological gaps needed to achieve multi-Hz operation with kJ-scale energy, paving the way for reactor-relevant drivers.

GO4: Develop the European laser fusion ecosystem.
This involves engaging academia, industry, and policymakers through workshops, schools, and industrial forums, while preparing the integration of the future facility conceptual design into the ESFRI roadmap and securing future support at both EU and national levels.

The success in fulfilling the above mentioned GOs will definitely advance the field of Inertial Fusion Energy in Europe, and indeed worldwide by increasing the maturity of the proposed approach while preparing the steps for the creation of a future direct-drive IFE laser facility in Europe. At the same time this will strengthen the whole field of fusion in Europe, strengthening research on reactor concepts, materials, tritium breeding, diagnostics development, …) in synergy with MCF. In this context we already started successful collaboration with several groups working in the domain of MCF (U.Bicocca and ENEA in Italy, IST in Portugal, ...)

Description and methodology.

The HiPER+RF project is focused at developing a conceptual design for a facility in Europe dedicated to DD and ICF. Four principal actions are related to our General Objectives (GO):

1. Develop a Conceptual Design for a European Direct-Drive Laser Fusion Facility (GO1, GO2, GO3)
The primary goal is to create a detailed conceptual design for a European Inertial Fusion Energy (IFE) facility. This facility will use the DD scheme, which is more energy-efficient and less complex than other methods. The project will generate crucial deliverables, including a validated, modular conceptual design suitable for a transition into the full engineering phase. It will also establish performance baselines for all subsystems, provide detailed subsystem designs, cost models, and a roadmap for future development, including industrial partnerships and funding strategies. These outcomes will serve as both scientific milestones and enablers for future investment.

2. Establish European Leadership in Inertial Fusion Energy (GO1, GO2, GO3, GO4)
The project aims to give Europe a leading role in the field of fusion energy by developing a complementary pathway to the historically more funded magnetic confinement fusion (MCF). By focusing on Direct Drive, Europe can overcome its current strategic disadvantage compared to countries like the United States and China and achieve future strategic autonomy in energy and advanced technologies.

3. Demonstrate Viability of Fusion as a Zero-Carbon Energy Source (GO1, GO2)

A long-term vision of the project is to build a civilian, open-access platform that can demonstrate the feasibility of inertial fusion as a sustainable, on-demand, and zero-carbon energy source. This involves creating a tightly integrated ecosystem that includes advanced diagnostics, scalable targetry, high-repetition laser technology, and materials capable of withstanding reactor-level stress.

4. Build and Integrate a European Laser Fusion Ecosystem (GO2, GO3, GO4)
The project also aims to develop and integrate a comprehensive ecosystem for laser fusion within Europe. This involves engaging a broad range of stakeholders, including academia, industry, and policymakers, through various forums, workshops, and schools. A key part of this objective is to secure support by preparing the conceptual design in view of the inclusion in the European Strategy Forum on Research Infrastructures (ESFRI) roadmap and establishing a stakeholder engagement platform to ensure long-term governance and funding commitments.

Building on the four main objectives, the HiPER+RF project is structured into seven interconnected work packages (WPs), each with subtasks designed to achieve the overall goals.

WP1: Project Management, Coordination, and Facility Conceptual Design
This work package coordinates and supervises all project activities to ensure delivery of the final conceptual design. Responsibilities include progress monitoring, resource reallocation, communication across all levels, and organization of technical, administrative, and general meetings to guarantee efficient and timely execution. WP1 constitutes the central management hub of the project, integrating oversight with the strategic development of the HiPER+RF facility's conceptual design.

- **Task 1.1:** Integrate all technical outputs from WPs 2-7 into a coherent facility design, including the laser hall, chamber layout, and diagnostics, the required subsystems and the overall architecture
- **Task 1.2:** Conduct trade-off analyses on various design options, among others chamber geometries and beamline layouts, to ensure a modular and upgradable design.
- **Task 1.3:** Create 3D CAD models of the facility and perform simulations for thermal loads, shielding, and mechanical stress of critical components. Explore AI-driven control schemes for autonomous operation.
- **Task 1.4:** Define and assess engineering constraints, including laser beam path, vacuum compatibility, and tritium handling. Deliver technical specifications for all utility systems, such as cooling loops and remote handling systems.
- **Task 1.5:** Nuclear analysis for safety in the conceptual design of the facility. Define licensing requirements according to nuclear safety regulations.
- **Task 1.6:** Conduct integrated design iterations with feedback from other WPs, including safety and logistics evaluations to support the pre-licensing phase.

WP2: Tailored Experiments
The primary objective of the project is to deliver the full conceptual design of a European IFE infrastructure, and this requires performing some dedicated experimental activities. These efforts will sustain and advance the consortium capabilities to supply tailored solutions for the conceptual design, building upon the achievements previously supported by ENR programs on DD. Major European laser laboratories within the consortium (LULI, PHELIX, PALS, and ELI-NP) will provide dedicated beam time, while collaborations with XFEL, ELI Beamlines, and ELI-ALPS will further enhance experimental capacity, also through dedicated access routes. This work package focuses on experimental validation, providing critical support to theoretical models and guiding design choices for the proposed facility.

- **Task 2.1:** Validate theoretical models and mitigation strategies for laser parametric instabilities (LPI) and for ablator dynamics and hydro instabilities through experiments at key European laser facilities (e.g., LULI, PHELIX, ELI) and non-European ones (e.g., NIF, Omega).
- **Task 2.2:** Coordinate with facility directors to secure beam time and ensure logistical feasibility.
- **Task 2.3:** Execute and coordinate experimental campaigns across multiple EU facilities, ensuring cross-calibrated diagnostics and shared data.
- **Task 2.4:** Develop a campaign strategy covering different energy regimes (single-beam, intermediate, high-energy) and establish pre-shot and post-shot data analysis pipelines.
- **Task 2.5:** Develop a coordinated data archiving and sharing strategy to promote open science and collaborative model refinement.

Task 2.6: Initiate bilateral experimental campaigns with international partners and publish open-access reports to harmonize protocols.

WP3: Laser Technology

The HiPER+RF project addresses key challenges in inertial confinement fusion (ICF) facility design by:
(i) increasing laser wall-plug efficiency to 7–15%,
(ii) demonstrating high-repetition-rate operation with ≥1 shot/min and potential multi-Hz capability, and
(iii) mitigating laser–plasma instabilities through broadband pulses, longer wavelengths (e.g. the 2nd harmonic of Nd lasers), and advanced beam smoothing.

This work package develops the high-efficiency, high-repetition-rate laser drivers essential for a fusion power plant.

Task 3.1: Develop a roadmap for Diode-Pumped Solid-State Laser (DPSSL) technology, including risk and cost analysis and scaling.

Task 3.2: Conceptual development of prototype laser subsystems, primarily amplifier modules and adaptive optics, in close collaboration with industry.

Task 3.3: Propose laser architectures for both single-shot and multi-Hz operation, evaluating different technologies and cooling methods.

Task 3.4: Define and model laser front-end stability and control, amplification noise, and thermal effects to ensure system resilience.

Task 3.5: Design scalable power conditioning and heat extraction systems.

Task 3.6: Partner with European photonics SMEs and research labs to co-design key components, fostering a European supply chain for fusion-class DPSSLs.

WP4: Targets, Materials, and engineering aspects

This activity defines the engineering specifications of the interaction chamber for ignition experiments, addressing licensing, target manufacturing, diagnostics, and debris management. It also evaluates reactor wall and blanket materials, and optical components under irradiation, while developing models, innovative designs, and industrial pathways to ensure safe, reliable, and cost-effective operation. The assessment of different concepts of blanket and vacuum vessels for the Fusion Power Plant in IFE will be performed, including the evaluation of tritium breeding solutions. In this WP we'll collaborate with companies and institutions working on targetry in Europe and able of providing foams, 3D printed structures, diamond shells, and other types of targets (e.g. UPNANO, Nanoscribe, Istituto Italiano di Tecnologia, Fraunhofer Institute, …)

This work package concentrates on the engineering and materials science aspects of the fusion chamber and target systems.

Task 4.1: Address the manufacturing, metrology, and injection of cryogenic DD targets. Define material specifications for the chamber walls and optics that can withstand harsh, repetitive neutron loads.

Task 4.2: Develop protocols for tritium handling and initiate pre-regulatory dialogue with tritium handling authorities. Study compatibility with chamber debris management systems, laser-generated Electromagnetic Pulses (EMPs) and propose preliminary specifications for breeding blankets.

Task 4.3: Assess high-volume target production methods, such as 3D printing and droplet injection, and propose automation protocols for quality assurance.

Task 4.4: Investigate target survivability during high-repetition-rate shots and define the interface for the target injector with the chamber timing systems.

Task 4.5: Conduct material testing for novel ablator materials and foam shells.

WP5: Laser-Plasma and Nuclear Fusion Diagnostics

This activity delivers the conceptual design of diagnostics for an ignition facility operating at high repetition rates in harsh environments. It develops methods to monitor target positioning, implosion dynamics, and ignition using optical, X-ray, particle-beam, and nuclear techniques. Existing systems at NIF and Omega will be reviewed in light of recent advances, with emphasis on direct-drive geometry to support ignition studies for the European scientific community.

This work package designs the advanced diagnostic systems required to monitor and control the fusion process under reactor-relevant conditions.

Task 5.1: Define diagnostic systems for laser plasma interaction, implosion performance, and reactor-scale operation, assessing them for radiation hardness, real-time readout, and EMP resilience.

Task 5.2: Benchmark diagnostic systems against those at existing facilities such as NIF and Omega and simulate their performance in the harsh environment.
Task 5.3: Map out diagnostics for key metrics like hot spot formation, neutron yield, and implosion symmetry.
Task 5.4: Test and validate radiation transport codes (Monte Carlo) and shielding standards.
Task 5.5: Develop protocols for radiation-induced drift correction and noise filtering, designing scalable readout electronics for high shot rates.
Task 5.6: Propose an industrial demonstrator program for sensor integration and prototyping under harsh conditions.

WP6: Physics

This work package establishes a comprehensive framework for the current state of laser fusion physics, with emphasis on direct-drive shock ignition (WP6.1–WP6.6), while also assessing alternative direct-drive schemes (WP6.7). This is of high importance to define, at the end of the project, updated solutions for the conceptual design following the most promising schemes and implementations.
This work package focuses on the theoretical and computational physics of direct-drive implosions, a central component of the project's strategy.

Task 6.1: Advance theoretical models for instabilities, imprint effect, alpha particle transport, and burn propagation, leading to validated target designs capable of a gain greater than 2 (Q>2).
Task 6.2: Validate new hydrodynamic models against experimental results.
Task 6.3: Model complex laser plasma interactions using integrated fluid-kinetic solvers and benchmark these tools against data from NIF and Omega.
Task 6.4: Perform detailed benchmarking of new 3D radiation hydrodynamics tools against historical data from major international facilities.
Task 6.5: Analyze the interplay between drive asymmetries and Rayleigh-Taylor growth. Train AI-based surrogate models to guide future design iterations.
Task 6.6: Define a new European standard for implosion performance metrics and collaborate internationally to refine capsule geometries.
Task 6.7: Explore and describe alternative approaches to direct drive, such as **fast ignition** and **magnetized ignition**, to broaden the project's scope and implosion facility design to allow also their implementation

WP7: Community Building and European Research Landscape Development

The HiPER+RF consortium will strengthen collaboration across the laser and nuclear fusion research community through strategic communication, training, and stakeholder engagement. Activities include dissemination of results, governance discussions, talent development via schools and workshops, and fostering broader cooperation within the European fusion landscape. The ultimate goal is to prepare the scientific and political foundations required for inclusion of HiPER+RF in the European Strategic Forum on Research Infrastructures (ESFRI) roadmap.
This work package focuses on building long-term community support and infrastructure beyond the conceptual design phase.

Task 7.1: Foster a coherent European IFE community through workshops, summer schools, and engagement with industry and policymakers.
Task 7.2: Maintain ongoing stakeholder engagement and track input from academia, industry, and government.
Task 7.3: Produce an ESFRI-compliant white paper to secure future support.
Task 7.4: Coordinate cross-border engagement through MOUs and joint PhD programs, aligning with broader European fusion strategies.
Task 7.5: Liaise with industrial consortia and policy platforms to prepare for ESFRI pre-application dossiers and the establishment of a formal legal entity.
Task 7.6: Propose a governance model for the future facility and develop talent retention strategies to prevent brain drain.

Strategic collaborations

The consortium participants collectively cover the necessary expertise across the relevant scientific and technological domains and maintain strong collaborative links with key national and international

partners. The breadth of competences and established networks within the consortium ensure that the programme can be implemented effectively and comprehensively. Moreover, from the CVs of the participants it is evident that the group possesses both the expertise and the connections, in Europe and beyond, to establish a strong scientific network that will further support and enhance the work of the consortium.
This being said, we will also welcome external contributions and indeed partnerships will be strengthened with European world-leading laser technology companies (Thales, Amplitude, …), European IFE start-ups (Marvel, GenF, Focused Energy, …), and with colleagues in the US and in the UK.
Also, since the project aims at reinforcing the IFE community in Europe, we will strengthen collaboration with major European facilities (Phelix, LULI, PALS, ELI, …), which indeed are already part of our project through the presence of several researchers or even facility directors. This is a prerequisite for an ambitious future research program, based on conducting tailored experiments in such facilities allowing to refine the target design. We also anticipate a close collaboration with the Helmholtz-Zentrum Dresden-Rossendorf, the European XFEL, and, in particular, with the three ELI pillars (which recently launched a call for programmatic experiments in the field of IFE). This call highlights the need for programmatic research in the field but also testifies the high interest in IFE all over European research facilities and scientific community.
Ultimately, full-scale experiments will be pursued at NIF and Omega in the US and at LMJ in France. It is important to notice that within Task W6.7 (magnetized ignition) already two experiments are planned respectively on Omega and NIF (PI Joao Santos), Beyond addressing specific problems in the field of magnetized inertial fusion, these experiments are useful to develop novel diagnostics approaches and consolidate numerical tools valid for all the field of IFE, and also to strengthen the collaboration within EU groups and between EU and the US.

Conclusive remarks

The **HiPER+RF proposal** charts a clear pathway toward a next-generation European facility capable of demonstrating fusion ignition via Direct Drive (DD) and paves the way to the future European IFE reactor, through a truly multidisciplinary scope —plasma physics, laser engineering, materials science, and community development [12]— to advance fundamental knowledge but also lay the technological and organizational foundations. In an era of intensifying international competition, this initiative offers Europe a strategic opportunity to lead in clean-energy innovation while building a resilient academic, industrial, and policy ecosystem around inertial fusion for civilian application.

The scientific case for DD extends well beyond power generation. Direct-drive systems provide access to high-energy-density plasmas not achievable in magnetic confinement devices, enabling breakthroughs in nuclear physics, astrophysics, and material science. In the long term, DD-based IFE may deliver reactors with smaller footprints, fewer cryogenic and magnetic constraints, and reduced capital costs. The proposed facility will thus serve as a European hub for frontier science while advancing a roadmap to scalable energy production.

In parallel, the project will play a key role in educating and training a new generation of fusion experts. across computational physics, optics, cryogenics, diagnostics, and regulatory science. This creates fertile ground for careers in academia and industry, while broadening Europe's fusion strategy beyond tokamaks. Such diversification strengthens the prospects for long-term energy sovereignty and aligns with the Green Deal, REPowerEU, and other decarbonization initiatives.

The facility will also act as a **steppingstone** toward a DEMO-class DD reactor. By starting with a research-scale installation, the project minimizes risks while maximizing returns in experimental data, community building, and validation of critical technologies. Its modular design ensures adaptability to rapid technological change and evolving stakeholder needs.

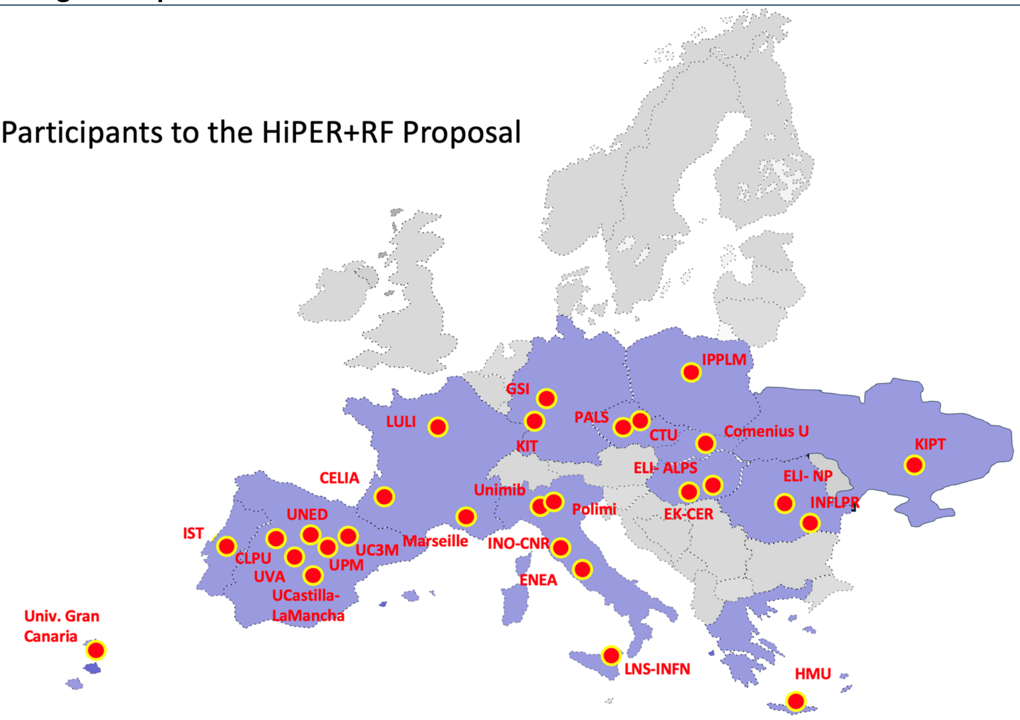
A **phased roadmap** will guide the transition from conceptual design to engineering development, prototyping, subsystem testing, and construction. Milestones will include metrics for technology readiness, procurement, and risk management. An exploitation plan will identify commercial spinoffs, industrial applications, training programs, and intellectual property strategies, ensuring alignment with ESFRI priorities and access to national and European co-funding.
Historically, inertial confinement fusion has been driven by military programs, particularly in the United States. Europe now has the opportunity to redefine this trajectory by establishing an open, civilian facility

for DD ignition and high-repetition experiments. The HiPER+RF initiative positions the EU at the forefront of peaceful fusion development, committed to transparency, collaboration, and scientific excellence. Achieving energy autonomy through fusion would represent a decisive step toward decarbonization, reduced dependence on imports, and scientific leadership in one of the defining technologies of the 21st century.

Future Vision and Long-Term Impact

The proposed facility could be realized by 2035 evolving into a fully operational research hub for high-gain, high-rep-rate inertial fusion, capable of producing scientific-grade neutron yields at multi-Hz rates. This would place Europe at the helm of a global shift in fusion energy technology. Beyond the immediate scientific goals, the facility could support broader impact areas such as nuclear forensics, advanced radiation therapy research, and the production of medical isotopes. Its design would also create spin-offs in high-power laser development, materials science, and AI-driven diagnostics. The long-term vision is to build the first civilian fusion testbed that can inform the development of a commercial-scale DD reactor within three decades.

Work and management plan



The HiPER+RF proposal involves almost the totality of the scientific civilian community working in inertial confinement fusion and related subjects. The map gives the extent of our collaboration showing how indeed we aim at federating different countries and research centers in a unified flagship project in the field of IFE. The management of such large project is of course a delicate issue, and it will be jointly addressed by the coordinator and the leaders of each participating group, among which we will choose some WP leaders. The work plan of the project is simply related to the realization of the conceptual design for a European High Power Laser Fusion Research Facility which based on i) direct drive, ii) international, iii) civilian. Hence the work plan is simple and structured as follows:

Year	Description
2026	Participating groups will carry out the activities defined in each Work Package (WP)
	Organization of the project’s General Meeting
	Close coordination with major European large-scale laser facilities to prepare future work, including experimental campaigns and political advocacy for IFE in Europe

	Organization of summer school, Participation to conferences
	Organization of an industry–academia forum involving European decision-makers
2027	Consolidation of results from all WPs into a unified conceptual design for a European High-Power Laser Fusion Research Facility, coordinated by WP1
	Promotion of political support within the European Union and at the national level for the establishment of the facility
	Submission, or preparation for submission, of proposals to ESFRI, Horizon Europe, and other relevant funding schemes
	Presentation of the final conceptual design at a major, dedicated, conference engaging academia, industry, and political stakeholders

The following table shows the involvement of various countries and research groups in each WP and in each specific task

Cts	Institutions	WP1	WP2	WP3	WP4	WP5	WP6	WP7
Cz	CTU Prague	2			5		2	1,4
	FZU-PALS	4	1-6		1	1,2,4	1,2	
Fr	CELIA	1-6	1,3			2,4	1,2,7	1,3,5,6
	LULI	2,3	1-6	2,3,5	3	2,3	1,2,3,6	5,6
	Univ Marseille	4	2				6	
Ge	GSI	4	1,2,6	1,3,6		1	1,7	1
	KIT	3	2,3	6	1,4	5,6	1,7	2
Gr	HMU	1,6	3		1	1	1,2,7	1-6
Hu	ELI-ALPS	4	2	2,4	4	6	1,6	1,5
	EK-CER	2,3	2	2,3,5,6				
It	UNIMIB	4			5	4		2
	ENEA	1,4,6	1,2,4,6	1,6	1,2,3	1,4,6	1,2,4,6	1,4,5,6
	INFN LNS	6	5		5	6	1	3,4
	INO CNR	1,6	1,3,6	1,3,6		1		1,3,5,6
	POLIMI	5	3		3,5	5	7	5
Pl	IPPLM	2	4		3	2,3	2,4	1,2
Po	IST-ID	2	5,6	1		3,4	1,2	1-4
Ro	ELI-NP	3	2,5	2,3	3	4,5,6	6	1,2,3
	INFLPR	3,5			2,5	3,6		4,5
Sp	ETSIAE-UPM	1,2	3,6			2,4	1,2,7	1,3,5
	INF-UPM	2,3,4	5		1,2,5		2	2,5,6
	UNED	3			2,5	4		5
	CLPU	2	5	2			1	1
	Univ GCanaria	4	3,4			2,4	3	4
	Univ CastillaLM	2	1				1,5	
	Univ C3M	3	1				1,5	
	Univ Valladolid	4	3,4			2,3	7	4
Ukr	NSC KIPT	3,4	1		1		1,3,7	
SL	Comenius Univ	3,4	6		1,4	4,5,6		1,3,5

Milestones

No	Description	Expected date
1	**Project Mobilization and Strategic Alignment:** Establish the project governance and coordination structure, ensuring effective inter-WP communication, and arrange agreements with facility partners to enable cross-facility experimental campaigns and data exchange.	2nd Trimester 1st year
2	physics models and simulation capabilities: laser–plasma interactions, hydrodynamic instabilities, and associated diagnostics for preliminary benchmarking, while also initiating the development of models and a computational framework to simulate facility-scale phenomena, including neutron shielding and thermal management.	3rd Trimester 1st year
3	**Experimental Validation and Data Acquisition:** Execute tailored experiment(s) at European laser facilities (e.g., ELI, LULI, PHELIX, PALS, …) to validate theoretical models for parametric instabilities mitigation and ablator dynamics with foams or alternative ablators, under controlled conditions.	4th Trimester 1st year
4	**System Specifications:** Initial conceptual design of the facility, with its layout and key subsystems (e.g., cooling, vacuum), diagnostics and evaluation of high-volume target production methods and their compatibility with the target injector system.	2st Trimester 2nd year
5	**Design of the laser Prototype**: Preliminary roadmap for Diode-Pumped Solid-State Laser (DPSSL) technology, with a physics-based risk analysis of scaling to fusion-relevant energies and repetition rates. Preliminary conceptual design of prototype laser system/subsystems, such as amplifier modules and adaptive optics, demonstrating performance metrics like gain, efficiency, and thermal stability in collaboration with industrial partners.	3rd Trimester 2nd year
6	**Integrated Modeling, Risk Mitigation, and Core Physics Validation:** Complete safety and logistics evaluations, including a preliminary assessment of environmental and regulatory requirements for a tritium-handling facility, and achieve the core scientific objective of validated target designs capable of gain greater than 2 (Q>2) through advanced simulation and available experimental data.	4th Trimester 2nd year

Governance and Risk Management

A critical point will be the management of such big ENR projects involving researchers from 10 European countries. This is important since, apart from delivering the conceptual design of a future facility, we want to strengthen the IFE community in Europe by working on a common ambitious project, something which lacked in the past. To fulfill this goal, we will establish a General Board (GB) which includes the main authors of the HiPER+ roadmap and representatives of the different research groups. The main goal of the GB will be to direct the work of various groups within the defined framework and assure the coherence of the program at all times. The work will be monitored by periodic meeting of the GB plus general meetings (first kick-off meeting followed by other two general meeting at mid-term and before competition of the project).

The committee will assure that roles and responsibilities will be defined clearly across beneficiaries and associated partners. WP leaders will be assigned within GB members.
The GB will also evaluate the risks and the mitigation measures (see table below). Risk management will follow a five-step process: identification, classification, mitigation, monitoring, and reassessment. Technical risks (e.g., integration delays) will be mitigated through redundancy and phased testing. Strategic

risks (e.g., loss of access to key facilities, shifts in policy support) will be addressed through stakeholder engagement and diversified collaborations. Each work package will maintain its own risk register.

Risks

No	Description	Mitigation measure(s)
1	Inefficient interaction and complementarity among partners due to the high number of participants	All partners members are used to work together in previous projects, and a regular, proper coordination processes will be implemented (WP1).
2	Compatibility of project results with EU and Member States regulations and standards	Analysis (WP2, WP6) of normative in nuclear regulations and evaluate the legal consideration of this type of facility
3	Finite lifetime of first wall and optics materials lifetime is too short and not compatible with commercialization of the laser fusion power plant	Consider additional methods of first wall and optics protection. Revise target design to reduce damaging effects. Consider technologies of fast replacement of damaged elements. Design more resistive materials.
4	DPSSL laser technology does not provide a commercially competitive laser fusion reactor design	Consider more efficient pumping schemes or other optically active materials. Design targets with a higher energy gain.
5	Target injection system cannot provide sufficiently accurate target positioning or synchronization	Develop a more precise target tracking system with laser feedback. Consider a system of dynamic laser alignment.
6	Laser Beam time not available. Risks associated with continuous operation of lasers	Multiple collaborations with several facilities mitigate this risk. Any delay can be controlled and supported by increasing the effort in other experiments.

Scientific Deliverables

Year	Description
2026	Intermediate Project Report on R&D needs to progress toward the engineering design including results from experimental activities
2027	Final conceptual design for a European High Power Laser Fusion Research Facility

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