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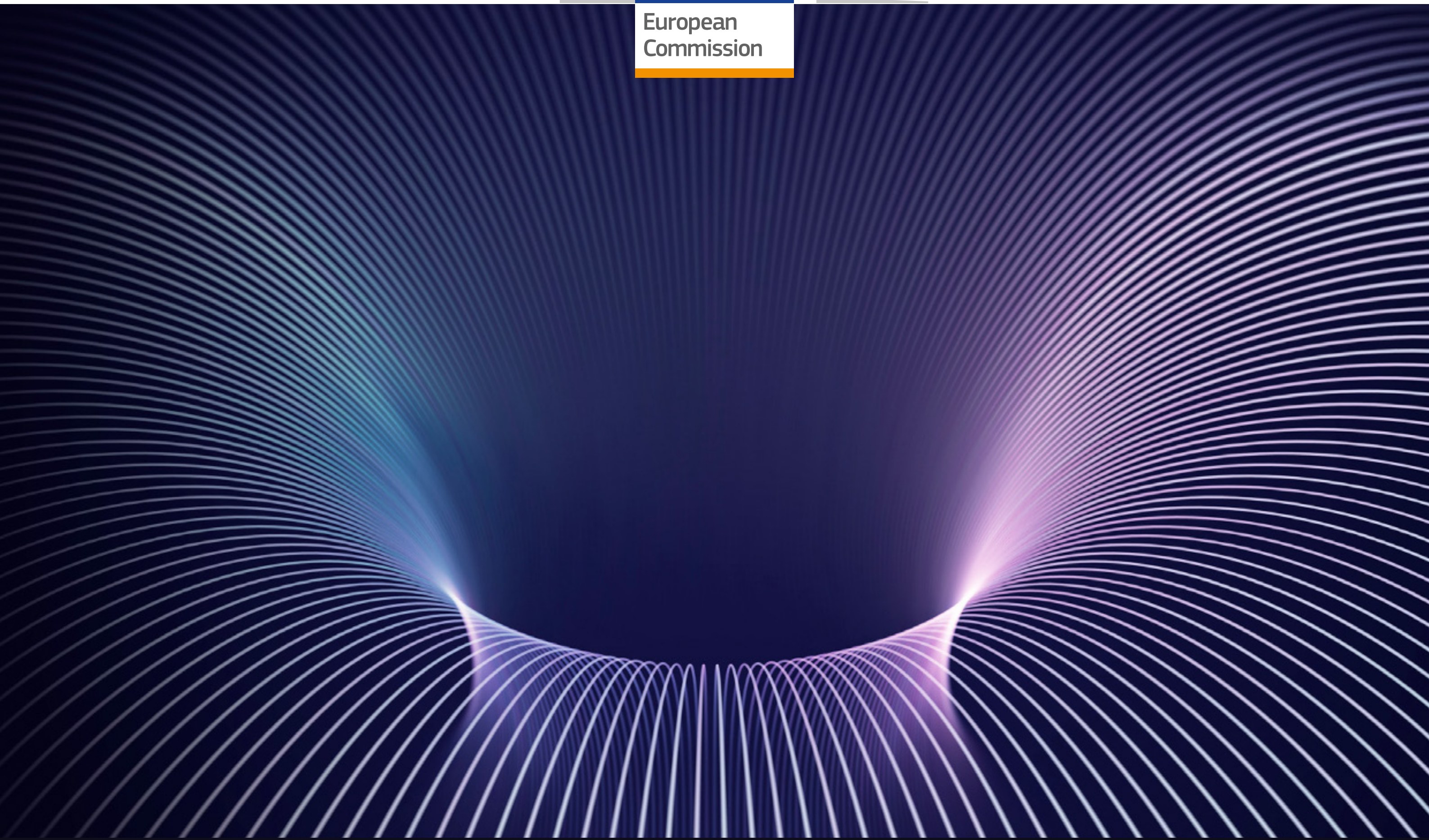

Analysis on a strategic public-private partnership approach to foster innovation in fusion energy

Final report

Energy

Contract details

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Presented by

Trinomics B.V.
Mauritsweg 44
3012 JV Rotterdam
The Netherlands

Contact person

Mr. Matthew Smith
T: +31 6 1292 9246
E: matthew.smith@trinomics.eu

Date

Rotterdam, 5th October 2023

Authors

Matthew Smith, Frank Gérard, Csinszka Bene, Shashwati Shankar, Andrea Finesso (Trinomics); Dr Matthew Moynihan (New Light Fusion); Dr Simon Woodruff (Woodruff Scientific); Dr Anika Stein.

Disclaimer

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Final Report

In association with:

Dr Matthew Moynihan (New Light Fusion)
Dr Simon Woodruff (Woodruff Scientific)
Dr Sehila M Gonzalez de Vicente
Dr Anika Stein
Dr Niek Lopes Cardozo
Maksym Semenyuk (DNV)
Bernd Rajal (Schoenherr)

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ABBREVIATIONS LIST

ARDP	Advanced Reactor Development Program [US]
BEPA	Batteries European Partnership Association
CEA	Commissariat à l'énergie atomique et aux énergies alternatives (The French Alternative Energies and Atomic Energy Commission) [FR]
CET	Clean Energy Transition [EU]
CfP	Call for Proposal
COTS	Commercial Orbital Transportation Services [NASA-US]
CPEP	Co-Programmed European Partnership
CSA	Coordination and Support Action
DEMO	Demonstration Fusion Power Plant
DG	Directorate General
DoE	Department of Energy [US]
DTT	Divertor Tokamak Test [EU-IT]
EIB	European Investment Bank
EIF	European Investment Fund
EIT-KIC	European Institute of Innovation and Technology – Knowledge and Innovation Community
F4E	Fusion for Energy
FES	(Office of) Fusion Energy Sciences
FIA	Fusion Industry Association
FIIF	Fusion Industry Innovation Forum
FOAK	First of a Kind
FPP	Fusion Power Plant
GVA	Gross Value Added
HPC	High Performance Computing
HTS	High-Temperature Superconductors (magnets)
IA	Innovation Actions
ICF	Inertial Confinement Fusion
IP	Intellectual Property
IPR	Intellectual Property Right
ITER	International Thermonuclear Experimental Reactor
JET	Joint European Torus
JU	Joint Undertaking
KDT	Key Digital Technologies
KET	Key Enabling Technologies
KIT	Karlsruhe Institute of Technology
KPI	Key Performance Indicator
MCF	Magnetic Confinement Fusion
NRC	Nuclear Regulation Committee
NIF	National Ignition Facility
PPP	Public Private Partnership
RDI	Research Development and Innovation
RIA	Research and Innovation Actions
SBRI	Small Business Research Initiative [UK]
SME	Small Medium Enterprise
SRIA	Strategic Research and Innovation Agenda
STEP	Spherical Tokamak for Energy Production [UK]
TDP	Technology Development Programme

TRL	Technology Readiness Level
UKAEA	UK Atomic Energy Authority

ABSTRACT

English

This study provides analysis and recommendations for the EC on the establishment of a public-private partnership approach to support industrial innovation in fusion in the EU. It is based on analysis of leading public-private partnership schemes to foster industrial innovation in the EU and globally, both for fusion and in other sectors. The study engaged closely with stakeholders through interviews, a workshop and focus groups to develop a clear understanding of the characteristics, needs, and interest of key stakeholders in the EU. The report provides a summary of the key lessons from existing programmes, the needs of stakeholders, the current policy and funding landscape and also the potential instruments within the EU under which a fusion PPP could best be based. It addresses the objectives of a potential PPP and specific design recommendations. In summary the study recommends the EC to pursue PPP arrangements in parallel through three instruments (a Co-Programmed European Partnership, F4E Innovation Partnerships and the EIT-KIC InnoEnergy) which each address different needs and are complementary towards achieving the proposed objectives. The objectives focus on supporting EU innovation on key enabling technologies for fusion with the goal to contribute to future DEMO design and development, maintain EU industrial know-how and competitiveness, and to leverage EU scientific leadership and the ITER project.

Français

Cette étude fournit une analyse et des recommandations à la CE sur la mise en œuvre d’une approche de partenariat public-privé (PPP) pour soutenir l’innovation industrielle dans le domaine de la fusion au sein de l’UE. Elle s’appuie sur l’analyse des principaux programmes de partenariat public-privé existants visant à encourager l’innovation dans l’UE et dans le monde, tant dans le domaine de la fusion que dans d’autres secteurs. L’étude a été réalisée en étroite collaboration avec les parties prenantes au moyen d’entretiens, d’un atelier et de groupes de discussion afin de bien comprendre les caractéristiques, les besoins et les intérêts des principaux acteurs européens dans le domaine de la fusion. Le rapport fournit une synthèse des principaux enseignements tirés des programmes existants, des besoins des parties prenantes, du paysage politique et financier actuel, ainsi que des instruments potentiels de l’UE qui pourraient servir de base à un PPP pour la fusion. Il introduit les objectifs d’un potentiel PPP et les recommandations spécifiques en matière de conception. En résumé, l’étude recommande à la CE de mettre en oeuvre un PPP à travers trois instruments (un partenariat européen dit co-programmé, les partenariats d’innovation de F4E et les appels à projets via l’EIT-CCI InnoEnergy) qui répondent chacun à des besoins différents et complémentaires pour atteindre les objectifs proposés. Les objectifs sont centrés sur le soutien à l’innovation au sein de l’UE dans le domaine des technologies clés de la fusion, afin de contribuer à la conception et au développement futurs de DEMO, de maintenir un savoir-faire et une compétitivité industrielles à l’échelle de l’UE, et en tirant parti du leadership scientifique de l’UE et du projet ITER.

EXECUTIVE SUMMARY

This project was commissioned by the European Commission DG ENERGY and carried out during 2023 by Trinomics and associated experts Woodruff Scientific, Dr Anika Stein, Dr Matthew Moynihan and Dr Niek Lopes Cardoso, with legal expertise provided by Schoenherr and quality review by DNV.

Study objectives and approach

Europe has a leading role in fusion research globally and as host to the ITER project has also made major industrial contributions to fusion innovation, investing billions of euros in the industry supply chain and research. However, there is a significant risk that the EU fusion know-how and industrial potential, developed over decades through this significant public investment, might be lost as investments in industrial innovation for ITER decline as it nears completion, and similar investments for DEMO remain more than 10 years in future. Furthermore, international competition is increasing with new public investment in fusion in other countries and a vibrant private sector emerging globally, both of which may also attract investments and expertise away from the EU.

To date, EU public investment in industrial innovation for fusion has primarily been through procurement contracts. However, there is also an increasing recognition that promoting a faster and viable commercialisation of fusion energy will require both public and private investment, that neither side will be able to achieve it alone. Public-private partnership (PPP) arrangements have been used successfully to promote industrial research and innovation in the EU in other fields, and in the US and elsewhere in fusion. An EU PPP for fusion may be able to address these needs for continued innovation and development, and retaining know-how, competitiveness and leadership in fusion, by creating an enabling environment for investment and growth of the emerging fusion innovation sector. This study investigated which lessons an EU PPP arrangement for fusion could draw from existing programmes and experience, and how these could be matched to the needs of stakeholders and the EU landscape.

The goals of this study were three-fold:

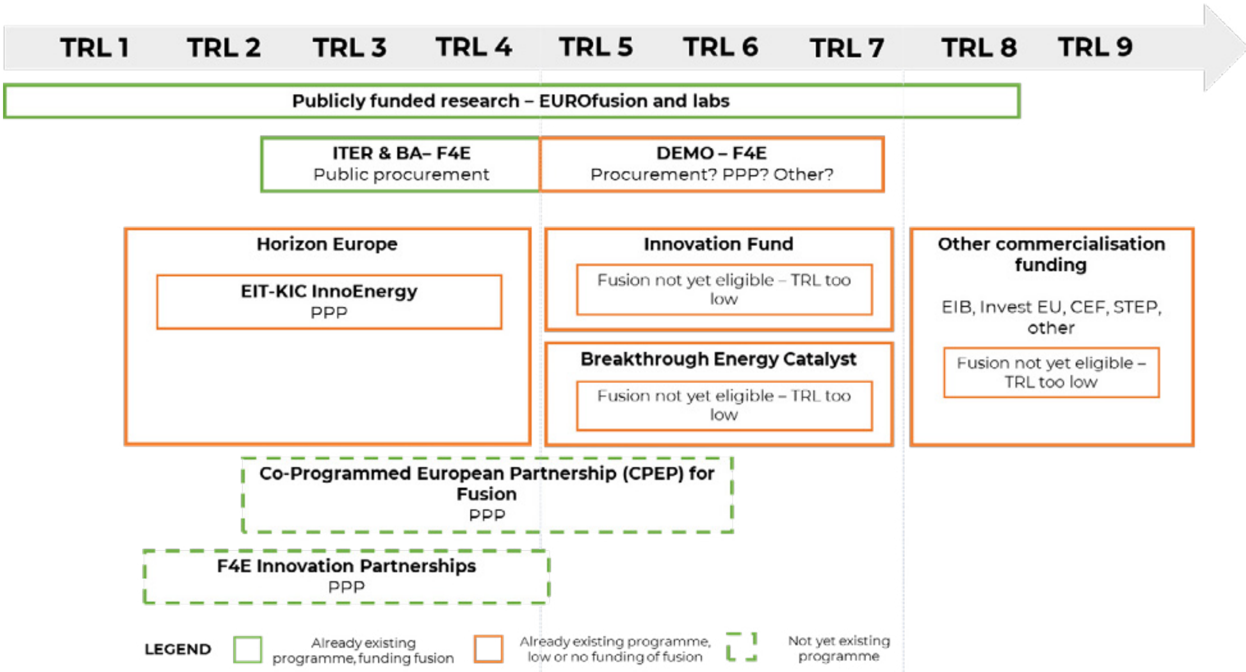
- Analysing PPP schemes around the world, both within and outside fusion energy, to inform the EC on an EU PPP design, understanding their key characteristics, strengths and weaknesses;
- Using the analysis of PPP schemes to set out the key design features of an EU PPP scheme for fusion energy which fits with the broader strategic, organisational, legal and financial context;
- Additionally, mapping and identifying stakeholders in the European fusion sector that are keen to engage in a PPP and further innovation in the field of fusion.

The study methodology combined desk review, interviews, workshops, and validation focus groups to inform the design of an EU PPP scheme for fusion energy.

Existing landscape and gaps for a PPP

The current EU funding landscape for fusion energy is summarized in Figure 0-1, where the main gaps are highlighted, i.e. whilst hundreds of millions are invested in ITER and related activities (e.g. Broader Approach, IFMIF-DONES) and EUROfusion which is focused on scientific research. The other instruments in the EU research and innovation funding landscape are either not yet active for fusion or not yet appropriate due to its low technological maturity in many areas. For example, whilst there are EU funding possibilities under Horizon Europe, including Partnership approaches, no fusion relevant programme exists. Other instruments such as the Innovation Fund and Breakthrough Energy Catalyst could also be opportunities, but these have a focus on more mature technologies, and the fact that fusion and many of its key enabling technologies (KETs) remain at a low maturity (TRL) rules out these instruments at this stage. This is even more true for instruments through the European Investment Bank, InvestEU, CEF and others. So far, the only identified instrument funding fusion outside the Euratom F4E and EUROfusion routes is the EIT-KIC InnoEnergy which has made a single investment in Novatron Fusion, a small Swedish start-up. The analysis shows that **there is an emerging gap in EU support for industrial innovation in fusion,** with the attendant risks to leadership, fusion development and competitiveness. This identifies a need for further EU funding and where a future EU PPP, for example as shown in the figure in the form of a Co-Programmed European Partnership (CPEP) and/or F4E Innovation Partnership, could be valuable to engage EU industry in continued fusion innovation.

Figure 0-1 Overview of fusion industrial innovation EU funding landscape



In addition to EC funding there are funding actions for fusion within the EU, in particular:

- In Germany which has launched a number of new fusion initiatives in 2023, unveiling new funding and a PPP instrument for inertial fusion under its SPRIND programme.
- In Italy where a public-private consortia is building the Divertor Tokamak Test project.

On the global stage, fusion research and funding have been accelerating, with new strategies, programmes and investments being announced in the last 2 years by the US, UK and Japan, whilst China also continues to invest heavily. In the US the approach is heavily PPP based, with an open technology approach and multiple programmes addressing fusion start-ups and research labs, intending for these to drive the industry forward. In the UK fusion funding is focused around developing research and innovation at the UKAEA site in Culham, with research institutes addressing multiple key enabling technologies for fusion, a PPP programme engaging industry in design and innovation work relevant for the development of STEP (the UK equivalent to DEMO) and private fusion start-ups also based around the UKAEA cluster.

Objectives for an EU PPP for fusion

Any potential EU Public-Private Partnership (PPP) approach to fusion should aim to create a stable and predictable framework for industrial innovation. The EC will need to define the primary objective for an

EU PPP for fusion energy, we outline potential paths in Section 4.2 of the report, with two key directions emerging for consideration:

- **DEMO as the primary objective:** this approach emphasizes partnerships between public research and engineering firms and accelerating conceptual design development for DEMO. It further leverages existing DEMO-focused work streams at F4E and EUROfusion.
- **Key Enabling Technologies (KETs) as the primary objective(s):** this approach directs attention toward addressing remaining key technical challenges, such as the tritium fuel cycle, first wall materials, remote handling, etc. It aligns with a long-term strategy toward fusion power plants and complements DEMO work streams. Additionally, it allows for a milestone-based program, attracting participation from the fusion supply chain and start-ups.

The objectives need to also consider how the PPP addresses:

- **Retaining flexibility** and adaptability to unforeseen events, potential delays to ITER, funding fluctuations, and shifts in technology focus.
- **Leveraging ITER** and the public and private know-how and experience gained in its construction and assembly both up to now and in-future.
- **Coherent development** which ensures that any programme is consistent with other activities carried out in the EU. A clear technology development roadmap or strategic research and innovation agenda should address this.
- **Technology transfer**, recognizing the significant scientific expertise within the fusion research community that can be applied and innovated further in collaboration with industry.
- **Supporting start-ups** is intricately linked to the chosen PPP objectives. Prioritizing DEMO construction may limit support and involvement of start-ups, while a more open approach aligns with good practice on mission led innovation and successful models from the US.
- **Ecosystem development**, contributing to EU industrial and scientific leadership and competitiveness.

Options for an EU PPP for fusion

We focused the analysis for an EU PPP for fusion on 3 main options. These were identified from the range of different instruments available and consideration of the potential for new instruments. Other instruments were typically ruled out as they would not be suited due to the low TRL of fusion as a whole and many of its sub-components, and new instruments were ruled out due to the lengthy processes these would take to establish. The analysis of the 3 options, the Co-Programmed European Partnership, EIT-KIC InnoEnergy and F4E Innovation Partnerships is summarised in Table 0-1 below (more details in section 4.2). This shows that all options have a positive assessment and have potential to address some part of the identified need.

Table 0-1 Summary and comparison of potential fusion PPP approaches

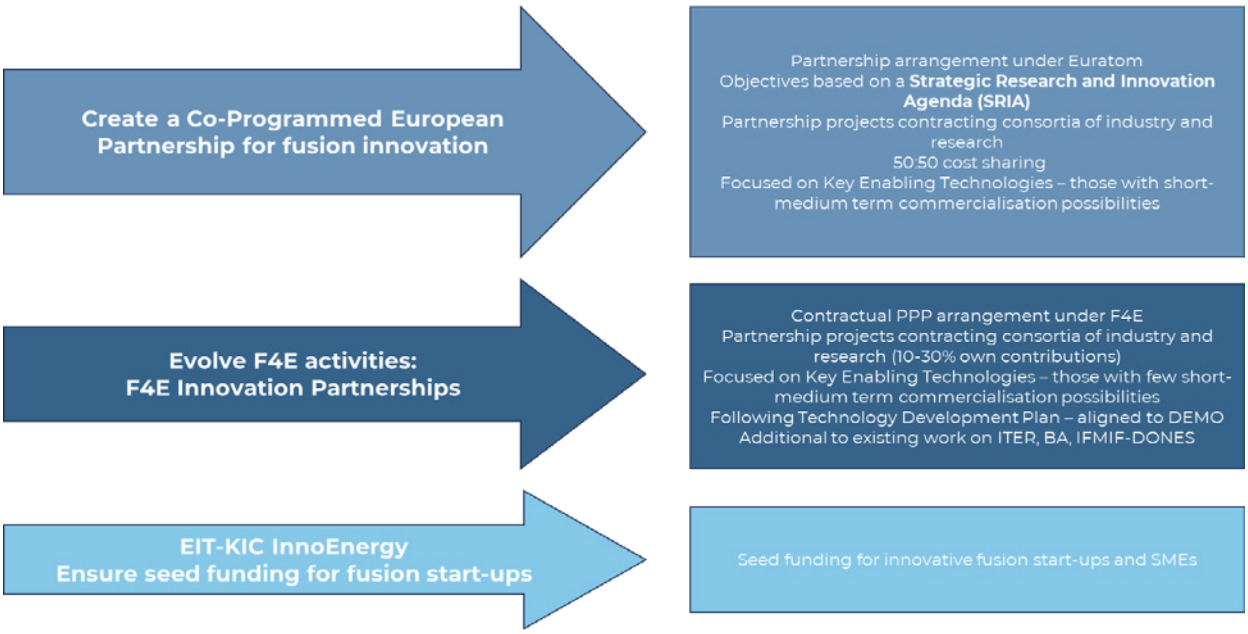
	Co-Programmed European Partnership (CPEP)	EIT-KIC – InnoEnergy (or similar)	F4E Innovation Partnerships
Short description	A CPEP is one of the four partnership types available within Horizon Europe. These are typically between the EC and private and public partners, and fund innovation activities on a 50:50 cost basis. Objectives, commitments and governance arrangements are set out in a Memoranda of Understanding between the parties, and a Strategic Research and Innovation Agenda sets the innovation goals and workplan for the partnership.	European Institute of Innovation and Technology (EIT) Knowledge and Innovation Communities (KIC) are one of the other Horizon Europe partnerships. These fund innovation projects, business incubators and accelerators, as well as training and education programmes. The primary partners are private companies (investors, industry, innovators), research organisations, educational institutions, and other stakeholders. The EIT-KIC typically makes a grant or equity investment in a partner organisation.	This is a contractual arrangement available to F4E which can be used as an alternative to procurement or grants. The arrangement could be used to share costs with industrial or research partners for industrial innovation projects which are in line with F4E objectives.
Advantages	• Significant potential funding available, could fund larger sub-projects • Formalised collaboration between industry, research and EC • Industry taking ownership and lead • Utilises proven existing funding and operational model • Strategic Research and Innovation Agenda jointly developed but aligned to EC goals • Model allows for various types of calls and potential focus areas	• Already active - has funded an EU fusion start-up already • Support to beneficiary is valuable – connecting to networks, investors, advice • Builds on private industry-led ideas • Technology neutral • No need for a fusion vision/strategy, only some budget allocation and potential commercial viability	• Contractual mechanism exists • Flexibility on matching contributions from industry • F4E possess the necessary procurement and technical expertise • Access to industrial network via ILOs • Objectives aligned with EU strategic objectives • Continuity from existing work on ITER • Potential to begin in the short-term

	Co-Programmed European Partnership (CPEP)	EIT-KIC – InnoEnergy (or similar)	F4E Innovation Partnerships
Disadvantages	• Requires matching contribution (time, resource, cash) from industry, at least equivalent to EU contribution • Requires additional activities from industry, not funded by the Partnership • Tied to EU Framework Programme processes which can be slow – unclear when it could be ready to launch, may only be for next MFF • Developing consensus on organisation and research agenda may take time	• Relatively limited funding available, also in competition with other RES under InnoEnergy • Suitability beyond start-ups and SMEs is unclear • Not necessarily aligned with EUROfusion roadmap	• Industry concerns about bureaucracy and repetition of 'heavy' ITER style procedures and F4E culture • Contract-based, which can be risky for industry (risk of not delivering) • Not inherently collaborative with fusion research community, may be unidirectional (F4E-industry) not a partnership • Political risk of spending F4E budget on non-ITER activities
Challenges	• Requires a single organisation to represent the sector (industry & research), this does not yet exist • Possible competition with other Partnerships for candidacy – need for political support in EC • Securing industry commitment to make matching contributions	• Securing sufficient scope for fusion within InnoEnergy • OR Starting a new EIT-KIC could be difficult and time-consuming	• Utilising a mechanism that has not been used • Securing funding within F4E – unclear if available budget would be sufficient • Justifying budgets externally in current ITER delays • Selecting the areas to focus on – can be alleviated with Technology Development Plan (TDP)

	Co-Programmed European Partnership (CPEP)	EIT-KIC – InnoEnergy (or similar)	F4E Innovation Partnerships
Overall conclusion	**Strong positive, albeit with challenges:** whilst this requires the greatest commitment and effort from industry (and the research community), it also provides the best potential in terms of funding, structure, flexibility, profile and focus. There are questions on how quickly this may be created when there is an urgency from the sector, waiting until the next MFF (2028-) would not be ideal.	**Positive, but with limitations:** this instrument offers a potentially effective mechanism to incubate further fusion start-ups, and potentially also SMEs in the fusion supply chain. This could complement a programme which focuses more heavily on industrial innovation on key enabling technologies.	**Positive, but with risks:** this instrument promises the potential to utilise existing structures, capacity and funds to spur industrial innovation in the short term. However, there are risks in the reprioritisation of F4E funding in the context of ITER.

Recommendations for an EU PPP for fusion

Based on the analysis of the fusion funding landscape, the needs of different stakeholders, the main options available and the urgency for action the following overview approach to funding fusion innovation in the EU is proposed. The rationale and accompanying recommendations are detailed further below and fully in chapters 4 and 5.



Evolve the focus of F4E funding to key enabling technologies: the existing procurement and work associated with ITER (and to a lesser extent Broader Approach) remains crucial to the role of F4E but as both move towards completion and operation the involvement of the industrial supply chain diminishes. The focus of F4E should also evolve towards its other objectives, namely towards DEMO and with this an increased focus on industrial innovation. Procurement of products and services from industry will continue to have a role in DEMO-related activities. However, there is also scope for an evolution in F4E activities, underpinned by its industrial policy. **We recommend that as soon as practical F4E starts a programme using the Innovation Partnership instrument to support industrial innovation in key enabling technologies**. We recommend the following characteristics apply to this F4E mechanism:

- It would reprioritise available F4E budgets, e.g. unspent from ITER, to use these towards F4E mandated objectives towards DEMO.
- Such a programme would target key enabling technologies of direct future relevance to DEMO – as determined in the F4E technology development plan (TDP), which should also align with the SRIA of the CPEP.
- The scope can be restricted to magnetic confinement approaches, but we would recommend that in addition to tokamak approaches, that technologies relevant for stellarators are also considered.
- The targeted technologies should primarily be those that do not have clear short-medium term (i.e. within 5-8 years) commercial possibilities or applications outside the fusion sector. Examples include: Tritium fuel cycle, heat exhaust systems.
- The possibility to move quickly is important for two key reasons: (1) to show quick wins of the new approach to EU fusion innovation funding; and, (2) as a pilot demonstration of the type of projects that may also be funded under the CPEP.
- Starting with a handful of pilot projects will also enable F4E to organise itself to effectively and efficiently select and administer such programmes, this may require a learning process compared to existing ITER procurement.
- To ensure a partnership approach some conditions need to be attached to the funding, including the necessity of at least one research partner in an innovation partnership; and the necessity of a contribution (in-kind or financial) to the overall cost to be made by the industry and research partners, i.e. it is not a grant/procurement contract.
- Given the focus on technologies further from market and/or with fewer applications outside fusion the expected contribution from industry is recommended to be in the range of only 10%-30% of total costs.
- An EC endorsement of this instrument and use of funds by F4E would reinforce the existing mandate that F4E has (towards DEMO and industrial innovation) and allow it to move forward with confidence.

Create a Co-Programmed European Partnership for fusion innovation under the Euratom framework to begin as soon as practical, ideally during the 2025-2027 work programme, but at least from the next MFF period in 2028. This would complement the F4E innovation partnership approach, but be distinct with the following characteristics:

- It should target a budget of tens of millions each year e.g EUR 30-100 million, potentially smaller budgets could be envisaged in the first years as the programme starts up. Larger budgets would very likely be necessary in future to cover the cost of large-scale technology development and demonstration.
- The Strategic Research and Innovation Agenda (SRIA) should target key enabling technologies overall, but with a focus on those with clearer short-medium term (i.e. within 5-8 years) commercial possibilities or applications outside the fusion sector. The rationale for this is based on the necessity of these commercial possibilities to attract industry and the necessary 50% matching contributions, and also for coherence with the proposed F4E instrument. Examples for focus include: Superconducting magnet manufacturing technologies, heating systems (gyrotrons, neutral beam injectors), remote handling systems.
- We recommend a split of around 75:25 in funding, with 75% reserved for key enabling technologies which are DEMO relevant, and 25% reserved for other fusion approaches, allowing for investment in technologies relevant for inertial fusion, magneto-inertial fusion or other magnetic confinement approaches. Reserving this smaller element provides a route for EU-firms with high-risk/high-potential approaches to scale.

- Activities for the main (75%) segment should be focused on development and demonstration projects. For the other approaches (25%) segment a broader variety of research activities could be foreseen, including for example, funding of INFUSE style innovation vouchers for firms to purchase time/expertise/knowledge from EU research institutions.
- The DEMO relevant part should also help to position the EU industry in global supply chains for all magnetic confinement based fusion approaches, i.e. so that EU industry can also be a leading supplier for public or private fusion devices in the US, UK, China, Japan or elsewhere.
- It would be the expectation that consortia bidding on the calls launched under this fusion PPP are led by industry, but include research partners. Start-ups could also be foreseen as consortia leads, not only for the alternative approaches segment of funding, but also in the mainstream magnetic confinement segment.
- CPEPs are typically required to be time-limited, aligning with the multi-annual financial framework periods. However, the need for a fusion PPP could extend all the way through to the construction and operation of a demonstration fusion power plant, i.e. possibly into the 2040's and 2050's. This should already be kept in mind when setting it up, particularly in the design of the Strategic Research and Innovation Agenda.
- Specifics on CPEP governance, process, IP rules are addressed separately.

Ensure a minimum of funding availability for fusion in the EIT-KIC InnoEnergy: the primary focus of this is to ensure there is a level of seed funding for fusion start-ups in the EU, this should include not only companies pursuing their own fusion approaches, but also SME's in the supply chain.

In future other instruments may also become relevant: the Innovation Fund, Breakthrough Energy Catalyst, EIB and other funds can all become more interesting in future as the TRL for fusion and the key enabling technologies increases. In the context of DEMO it may also become interesting to explore the creation of a specific company or partnership under Euratom to finance the construction, this is unlikely to be relevant before 2030.

Note: it is important to mention that the proposed PPP approach is developed on the basis that it has no impact on the ongoing work of EUROfusion nor on F4E work on ITER, BA, IFMIF-DONES, i.e. any PPP would be additional. Therefore the existing work carried out via EUROfusion should continue unchanged, this includes the scientific work at the lowest TRLs for key enabling technologies, and the early conceptual and design work for DEMO. The primary target group of EUROfusion funding is the research community, but industry also has a small involvement, as a supplier, for example through framework contracts to support the DEMO concept and design work. The funding from EUROfusion is also crucial to continue to develop and train a pipeline of staff for the sector as a whole.

Chapter 5 of this report provides further specific details on what these recommendations mean for each stakeholder type and DEMO.

Recommended actions for the EC

There are a few key steps that need to be taken, and a role for the EC in each of them:

Establishing the policy backing for a Fusion CPEP. We understand that if a decision to go-ahead is made, that it would be created under Euratom auspices and therefore would not need to go through the current Horizon Europe candidate partnership selection process. However, the necessary arrangements by EC services will still need to be made to ensure that a CPEP (under Euratom) could begin as soon as possible within the next few years.

Communicate with industry and support the establishment of an EU representative organisation for the CPEP. The EC should speak with industry and make clear that the industry needs to organise itself in a way that is consistent with a CPEP. **A Coordination and Support Action**

(CSA) could be used to support industry and the research community in a process to establish such an organisation. However, this may slow down the process and a faster alternative without support could be promoted with stakeholders. This should utilise both the Fusion Industry Innovation Forum (FIIF) and Fusion Industry Association (FIA), and should also make use of F4E and their Industrial Liaison Officer networks, with also EUROfusion involved. The EC does not need to be directly involved in the formation of an EU fusion industry trade association (distinct from the organisation to run the CPEP) as part of this process, but it could be a welcome additional outcome.

Propose a Strategic Research and Innovation Agenda (SRIA) and work with stakeholders to finalise it. Taking a step towards an EU fusion innovation strategy (see below), the EU should propose a SRIA which defines the main areas of focus and milestones to be achieved and also emphasises how the CPEP should contribute to accelerating fusion innovation and supporting industry. It also needs to be consistent and coherent with the other instruments and ongoing activities. Following the process outlined in 4.3.1 the SRIA should be discussed and refined with the industry and research stakeholders of the CPEP to further detail and refine towards a final agreed SRIA, this could be as part of the CSA noted above.

Give policy backing for F4E Innovation Partnerships. Whilst F4E already has a mandate for work towards DEMO, there could be sensitivities on reprioritisation of F4E budgets towards DEMO-oriented activities, particularly in the context of ITER delays. Receiving EC backing to take this route would bolster F4E to take action. The EC should review the F4E Technology Development Plan (TDP) to ensure consistency and coherence across the proposed PPP instruments.

Establish a route for start-ups to access seed funding in EIT-KIC InnoEnergy. As part of EIT-KIC InnoEnergy or a similar mechanism the EC should verify and, if possible, ensure that sufficient funding is available to invest in fusion start-ups in the EU. Start-ups would also be eligible to participate in the proposed CPEP and F4E instruments.

Develop an EU innovation strategy for fusion. An over-arching EU fusion vision or strategy was a clear request from stakeholders throughout the work. Whilst a full strategy may not be feasible at this point, at least a fusion innovation strategy is needed which defines and ties together which innovation objectives should be achieved, how and which instruments should be used for each. This should also take into account national programmes. An EU innovation strategy for fusion will help to set a positive and coherent landscape for fusion innovation across the EU and also define the role of the main stakeholders and each of the instruments to be used.

RÉSUMÉ EXÉCUTIF (FR)

Ce projet a été commandé par la DG ENERGIE de la Commission européenne et réalisé au cours de l'année 2023 par Trinomics et les experts associés Woodruff Scientific, le Dr Anika Stein, le Dr Matthew Moynihan et le Dr Niek Lopes Cardoso. L'expertise juridique a été fournie par Schoenherr et l'evaluation de la qualité par DNV.

Objectifs et approche méthodologique de l'étude

L'Europe joue un rôle de premier plan dans la recherche sur la fusion à l'echelle mondiale et, en tant qu'hôte du projet ITER, a également apporté d'importantes contributions industrielles à l'innovation en matière de fusion, en investissant des milliards d'euros dans la chaîne d'approvisionnement industrielle et dans la recherche. Cependant, le savoir-faire et le potentiel industriel de l'UE en matière de fusion, développés au fil des décennies grâce à ces investissements publics considérables, risquent de connaitre un déclin marqué dans la mesure où les investissements dans l'innovation industrielle pour ITER diminuent à mesure que sa construction s'achève, et que des investissements similaires pour DEMO ne seront pas deployés avant une dizaine d'années , voire plus. En outre, la concurrence internationale s'intensifie avec de nouveaux investissements publics et l'émergence d'un secteur privé dynamique à l'échelle mondiale, deux facteurs susceptibles d'attirer des investissements et des compétences en dehors de l'UE.

Jusqu'à présent, les investissements de l'UE dans l'innovation industrielle pour la fusion ont principalement pris la forme de marchés publics. Cependant, il est de plus en plus reconnu qu'une commercialisation plus rapide et plus viable de l'énergie de fusion nécessitera des investissements publics et privés, et qu'aucune des deux parties ne pourra y parvenir seule. Les partenariats public-privé (PPP), dans d'autres domaines, ont été utilisés avec succès pour promouvoir la recherche et l'innovation industrielles dans l'UE, ainsi qu'aux États-Unis et ailleurs que dans le domaine de la fusion. Un PPP européen pour la fusion pourrait répondre à ces besoins d'innovation et de développement continus, et de conserver le savoir-faire, la compétitivité et le leadership dans ce domaine, en créant un environnement propice à l'investissement et à la croissance du secteur émergent de la fusion. Cette étude a examiné les leçons qu'un PPP européen pour la fusion pourrait tirer des programmes et expériences existants, et comment celles-ci pourraient être adaptées aux besoins des parties prenantes et au paysage de l'UE.

Les objectifs de cette étude étaient triples :

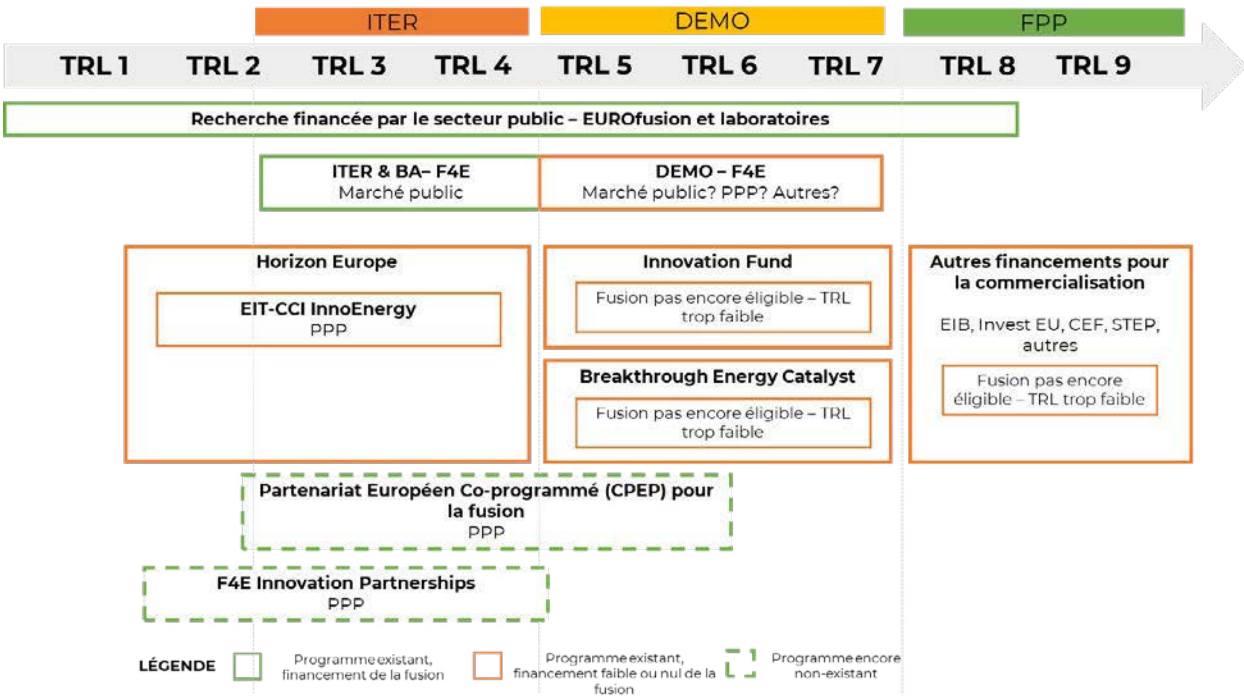
- Analyser les projets PPP à travers le monde, tant dans le domaine de l'énergie de fusion qu'en dehors, afin d'informer la Commission européenne (CE) sur la conception d'un PPP européen, en prenant en compte leurs principales caractéristiques, forces et faiblesses ;
- Utiliser l'analyse des différents systèmes de PPP pour définir les principales caractéristiques de conception d'un PPP européen pour l'énergie de fusion qui s'adapte plus largement au contexte stratégique, organisationnel, juridique et financier;
- Enfin, de cartographier et d'identifier les parties prenantes du secteur européen de la fusion qui souhaitent s'engager dans un PPP et poursuivre l'innovation en matière de fusion.

La méthodologie utilisée pour mener à bien cette étude combinait une revue de la littérature, des entretiens, des ateliers et des groupes de discussion afin d'éclairer la conception d'un système PPP europpéen pour l'énergie de fusion.

Paysage actuel et lacunes pour un PPP

Le paysage actuel en matière de financement par l'UE pour l'énergie de fusion est résumé dans la Figure 0-1, où les principales lacunes sont également mises en évidence: des centaines de millions sont investis dans le projet ITER et dans les activités connexes (par exemple, Approche Elargie, IFMIF-DONES) ainsi que dans EUROfusion, axé sur la recherche scientifique. Les autres instruments de financement de la recherche et de l'innovation ne sont pas encore actifs pour la fusion ou ne sont pas encore adaptés en raison de leur faible maturité technologique dans de nombreux domaines. Par exemple, bien qu'il existe des possibilités de financement par l'UE dans le cadre d'Horizon Europe, y compris des approches de partenariat, il n'existe aucun projet concernant la fusion. D'autres instruments, tels que le Fonds d'innovation et *Breakthrough Energy Catalyst*, pourraient également constituer des opportunités de financement, mais ils se concentrent sur des technologies plus matures, et le fait que la fusion et bon nombre de ses technologies clés (KET, Key Enabling Technologies en anglais) restent à un niveau de maturité (TRL) faible exclut ces instruments à ce stade. Cela est encore plus vrai pour les instruments de la Banque européenne d'investissement, InvestEU, CEF et autres. Jusqu'à présent, le seul instrument identifié pour financer la fusion en dehors des voies Euratom F4E et EUROfusion est l'EIT-CCI InnoEnergy qui a réalisé un seul investissement dans Novatron Fusion, une start-up suédoise. L'analyse montre qu'il **existe une lacune émergente dans le soutien de l'UE à l'innovation industrielle dans le domaine de la fusion,** avec les risques qui en découlent pour le leadership, le développement de la fusion et la compétitivité industrielle. Il en ressort un besoin de financement supplémentaire de la part de l'UE et la nécessité d'un futur PPP européen, par exemple comme le montre la figure sous la forme d'un partenariat européen dit Co-programmé (CPEP, *Co-Programmed European Partnership* en anglais) et/ou d'un partenariat d'innovation F4E, pour impliquer l'industrie de l'UE dans l'innovation continue en matière de fusion.

Figure 0-1 Vue d'ensemble du paysage du financement par l'UE de l'innovation industrielle en matière de fusion



Outre le financement de la CE, il existe des financements pour la fusion au sein de l'UE, notamment:

- En Allemagne, où un certain nombre de nouvelles initiatives en matière de fusion ont été lancées en 2023, dévoilant de nouveaux financements et un instrument PPP pour la fusion inertielle dans le cadre de son programme SPRIND.
- En Italie, où un consortium public-privé construit le projet Divertor Tokamak Test (DTT).

Sur la scène mondiale, la recherche et le financement sur la fusion se sont accélérés, avec de nouvelles stratégies, de nouveaux programmes et investissements annoncés au cours des deux dernières années par les États-Unis, le Royaume-Uni et le Japon. La Chine continue également d'investir massivement. Aux États-Unis, l'approche est fortement basée sur les PPP, avec une approche technologique inclusive et de multiples programmes destinés aux start-ups et aux laboratoires de recherche dans le domaine de la fusion, dans le but de faire progresser l'industrie. Au Royaume-Uni, le financement de la fusion est axé sur le développement de la recherche et de l'innovation sur le site de l'UKAEA à Culham, avec des instituts de recherche abordant plusieurs technologies clés pour la fusion, un programme PPP engageant l'industrie dans des travaux de conception et d'innovation pertinents pour le développement de STEP (l'équivalent britannique de DEMO) et des start-ups privées de fusion également basées autour du cluster de l'UKAEA.

Objectifs d'un PPP européen pour la fusion

Toute approche potentielle de partenariat public-privé (PPP) européen en matière de fusion devrait viser à créer un cadre stable et prévisible pour l'innovation industrielle. La CE devra définir l'objectif principal d'un PPP européen pour l'énergie de fusion. Nous décrivons les voies potentielles dans la section 4.2 du rapport, avec deux orientations clés à prendre en considération :

- **DEMO comme objectif principal :** cette approche met l'accent sur les partenariats entre la recherche publique et les sociétés d'ingénieurie pour accélérer la conception de DEMO. Elle exploite davantage les flux de travail existants centrés sur DEMO chez F4E et EUROfusion.
- **Technologies clés (KET) comme objectif(s) principal(s) :** cette approche vise à relever les principaux défis techniques restants, tels que le cycle du combustible au tritium, les matériaux des parois internes des réacteurs à fusion, la manipulation à distance, etc. Elle s'inscrit dans le cadre d'une stratégie à long terme vers les centrales électriques à fusion et complète les axes de travail de DEMO. De plus, elle permet de mettre en place un programme basé sur des étapes, attirant la participation d'acteurs provenant de la chaîne d'approvisionnement de la fusion et des start-ups.

Les objectifs doivent également prendre en compte la manière dont le PPP aborde les problématiques suivantes :

- **Conserver la flexibilité** et l'adaptabilité aux événements imprévus, aux retards potentiels d'ITER, aux fluctuations du financement et aux changements d'orientation technologique.
- **Tirer parti d'ITER** ainsi que du savoir-faire et de l'expérience publics et privés acquis dans sa construction et son assemblage, aujourd'hui et à l'avenir.
- **Un développement approprié** qui garantit que tout programme est cohérent avec d'autres activités menées dans l'UE. Une feuille de route claire pour le développement technologique ou un programme stratégique de recherche et d'innovation devrait répondre à cet objectif**.**
- **Un transfert de technologie**, reconnaissant l'expertise scientifique significative au sein de la communauté de recherche sur la fusion qui peut être appliquée et innovée davantage en collaboration avec l'industrie.
- **Le soutien aux start-ups** est étroitement lié aux objectifs choisis du PPP. Donner la priorité à la construction de DEMO peut limiter le soutien et l'implication des start-ups, tandis qu'une approche plus ouverte s'alignerait sur les bonnes pratiques en matière d'innovation menée par la mission et les modèles réussis aux États-Unis.
- **Développement de l'écosystème**, contribuant au leadership scientifique et à la compétitivité industrielle de l'UE.

Options pour un PPP européen pour la fusion

Nous avons concentré l'analyse d'un PPP européen pour la fusion sur trois options principales. Celles-ci ont été identifiées sur base des différents instruments disponibles et de l'examen du potentiel de nouveaux instruments. Certains instruments existants ont été écartés de l'analyse car ils ne seraient pas adaptés en raison du faible TRL de la fusion dans son ensemble et de bon nombre de ses sous-composants. De nouveaux instruments ont également été écartés en raison des longs processus qu'ils nécessiteraient pour être mis en œuvre. L'analyse des trois options, le Partenariat Européen Co-programmé (CPEP), l'EIT-CCI InnoEnergy et les partenariats d'innovation F4E, est résumée dans le Tableau 0-1 (plus de détails dans la section 4.2). Il en ressort que toutes les options ont fait l'objet d'une évaluation positive et sont susceptibles de répondre en partie aux besoins identifiés.

Tableau 0-1 Résumé et comparaison des approches potentielles pour un PPP européen pour la fusion

	Partenariat Européen Co-programmé (CPEP)	EIT-CCI - InnoEnergy (ou similaire)	Partenariats d'innovation F4E
Description	Le CPEP est l'un des quatre types de partenariat disponibles dans le cadre d'Horizon Europe. Il s'agit généralement d'un partenariat entre la CE et des partenaires privés et publics, qui finance des activités d'innovation sur une base de 50/50. Les objectifs, les engagements et les modalités de gouvernance sont définis dans un protocole d'accord entre les parties, et un programme stratégique de recherche et d'innovation fixe les objectifs d'innovation et le plan de travail du partenariat.	Les communautés de la connaissance et de l'innovation (CCI) de l'Institut européen d'innovation et de technologie (EIT) sont l'un des autres partenariats d'Horizon Europe. Elles financent des projets d'innovation, des incubateurs et des accélérateurs d'entreprises, ainsi que des programmes de formation et d'éducation. Les principaux partenaires sont des entreprises privées (investisseurs, industrie, innovateurs), des organismes de recherche, des établissements d'enseignement et d'autres parties prenantes. L'EIT-CCI accorde généralement une subvention ou une participation au capitale d'une organisation partenaire.	Il s'agit d'un accord contractuel dont dispose F4E et qui peut être utilisé comme alternative aux marchés publics ou aux subventions. Il peut être utilisé pour partager les coûts avec des partenaires industriels ou de recherche dans le cadre de projets d'innovation industrielle conformes aux objectifs de F4E.

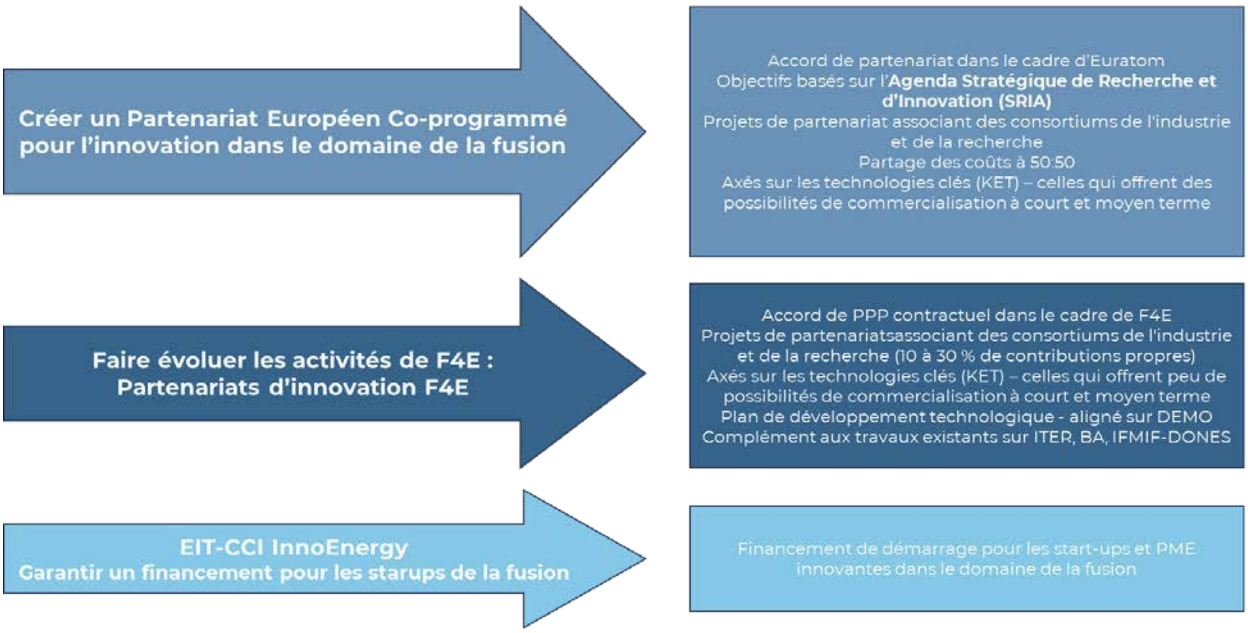
	Partenariat Européen Co-programmé (CPEP)	EIT-CCI – InnoEnergy (ou similaire)	Partenariats d'innovation F4E
Avantages	• Un financement potentiel important est disponible, il pourrait financer des sous-projets plus importants. • Collaboration formalisée entre l'industrie, la recherche et la CE • L'industrie prend en charge et dirige le projet • Utilise un modèle de financement et d'exploitation existant qui a fait ses preuves • Agenda stratégique pour la recherche et l'innovation élaboré conjointement mais aligné avec les objectifs de la CE • Le modèle permet de prendre en compte différents types d'appels et de domaines d'intervention potentiels.	• Déjà actif - a déjà financé une start-up de l'UE dans le domaine de la fusion • L'aide aux bénéficiaires est précieuse - mise en relation avec des réseaux, des investisseurs, des conseils • S'appuie sur des idées émanant de l'industrie privée • Neutre du point de vue technologique • Il n'est pas nécessaire d'avoir une vision/ stratégie de fusion, mais seulement une allocation budgétaire et une viabilité commerciale potentielle.	• Mécanisme contractuel existant • Flexibilité sur les contributions de contrepartie de l'industrie • F4E possède l'expertise technique et contractuelle nécessaire • Accès au réseau industriel via les agents de liaison industrielle (ILO, Industrial Liaison Officer en anglais) • Objectifs alignés avec les objectifs stratégiques de l'UE • Continuité avec les travaux existants sur l'ITER • Possibilité de commencer à court terme

	Partenariat Européen Co-programmé (CPEP)	EIT-CCI – InnoEnergy (ou similaire)	Partenariats d'innovation F4E
Inconvénients	• Nécessite une contribution équivalente (temps, ressources, budget) de la part de l'industrie, au moins équivalente à la contribution de l'UE • Nécessite des activités supplémentaires de la part de l'industrie, qui ne sont pas financées par le partenariat • Lié aux processus du Programme-cadre de l'UE, qui peuvent être lents – incertitude sur quand il sera prêt à être lancé, peut-être seulement pour le prochain cadre financier pluriannuel (CFP) • L'obtention d'un consensus sur l'organisation et le programme de recherche peut prendre du temps	• Financement disponible relativement limité, également en concurrence avec d'autres SER dans le cadre d'InnoEnergy • L'adéquation au-delà des start-ups et des PME n'est pas claire. • Pas nécessairement aligné sur la feuille de route d'EUROfusion en matière de fusion	• Préoccupations de l'industrie concernant la bureaucratie et la répétition des procédures "lourdes »" du type ITER et de la culture F4E • Basé sur des contrats, ce qui peut être risqué pour l'industrie (risque de non-respect des engagements) • La collaboration avec la communauté de la recherche sur la fusion n'est pas intrinsèque, elle peut être unidirectionnelle (F4E-industrie), il ne s'agit pas d'un partenariat. • Risque politique lié à l'affectation du budget F4E à des activités ne relevant pas de ITER
Défis	• Nécessite une organisation unique pour représenter le secteur (industrie et recherche), ce qui n'existe pas encore • Concurrence possible avec d'autres partenariats pour la candidature – nécessité d'un soutien politique au sein de la CE • Obtenir l'engagement de l'industrie à verser des contributions équivalentes	• Assurer une marge de manœuvre suffisante pour la fusion au sein d'InnoEnergy • OU La création d'un nouvel EIT-CCI pourrait s'avérer difficile et chronophage	• Utilisation d'un partenariat nouveau • Assurer le financement dans le cadre de F4E – il n'est pas certain que les budgets disponibles soient suffisants • Justifier les budgets à l'extérieur dans les délais actuels de ITER • Sélection des domaines sur lesquels se concentrer – peut être atténuée par un plan de développement technologique (PDT)

	Partenariat Européen Co-programmé (CPEP)	**EIT-CCI - InnoEnergy (ou similaire)**	**Partenariats d'innovation F4E**
Conclusion générale	**Fortement positif, bien qu'il y ait des défis à relever :** malgré que cela nécessite un engagement et des efforts importants de la part de l'industrie (et du secteur de la recherche), cette option offre également le meilleur potentiel en termes de financement, de structure, de flexibilité, de profil et d'orientation. Des questions se posent quant à la rapidité de création d'un tel programme lorsque le secteur fait face à un degré d'urgence important ; il ne serait pas idéal d'attendre le prochain CFP (2028-).	**Positif, mais avec des limites :** cet instrument offre un mécanisme potentiellement efficace pour incuber d'autres start-ups dans le domaine de la fusion, et éventuellement aussi des PME dans la chaîne d'approvisionnement de la fusion. Il pourrait compléter un programme qui se concentre davantage sur l'innovation industrielle dans le domaine des technologies clés de la fusion.	**Positif, mais avec des risques :** cet instrument offre la possibilité d'utiliser les structures, les capacités et les fonds existants pour stimuler l'innovation industrielle à court terme. Toutefois, la redéfinition des priorités du financement de F4E dans le contexte d'ITER comporte des risques.

Recommandations pour un PPP européen dans le domaine de la fusion

Sur la base de l'analyse du paysage du financement de la fusion, des besoins des différentes parties prenantes, des principales options disponibles et de l'urgence d'agir, l'approche générale suivante est proposée pour soutenir l'innovation dans le domaine de la fusion au sein de l'UE. Le raisonnement et les recommandations qui l'accompagnent sont détaillés ci-dessous et de manière plus detaillée dans les chapitres 4 et 5.



Faire évoluer l'orientation du financement de F4E vers des technologies clés (KET) : les marchés publics existants et les travaux associés à ITER (et, dans une moindre mesure, à l'Approche Elargie) restent essentiels pour le rôle de F4E, mais à mesure que les deux projets se rapprochent de l'achèvement et de l'exploitation, la participation des acteurs de la chaîne d'approvisionnement industrielle diminue. L'objectif de F4E devrait également évoluer vers ses autres objectifs, à savoir DEMO et, par conséquent, une plus grande attention portée à l'innovation industrielle. L'acquisition de produits et de services auprès de l'industrie continuera à jouer un rôle dans les activités liées à DEMO. Toutefois, les activités de F4E peuvent également évoluer, en s'appuyant sur sa politique industrielle. **Nous recommandons que F4E lance dès que possible un programme utilisant l'instrument du Partenariat d'innovation afin de soutenir l'innovation industrielle dans les technologies clés (KET)**. Nous recommandons que les caractéristiques suivantes s'appliquent à ce mécanisme de F4E :

- Les priorités des budgets disponibles de F4E devraient être redéfinies, par exemple les budgets d'ITER qui n'ont pas été dépensés, afin de les utiliser pour les objectifs de DEMO mandatés par F4E.
- Un tel programme ciblerait les technologies clés (KET) présentant un intérêt futur direct pour DEMO - comme déterminé dans le plan de développement technologique (PDT) de F4E, qui devrait également s'aligner sur les SRIA du CPEP.
- Le champ d'application peut être limité aux approches de confinement magnétique, mais nous recommandons qu'en plus des approches de tokamak, les technologies pertinentes pour les stellarators soient également prises en compte.
- Les technologies ciblées devraient principalement être celles qui n'ont pas de possibilités commerciales ou d'applications claires à court et moyen terme (c'est-à-dire dans les 5 à 8 ans) en dehors du secteur de la fusion. Exemples : cycle du combustible au tritium, systèmes d'échappement thermique.
- La possibilité d'agir rapidement est importante pour deux raisons : (1) pour montrer les résultats rapides de la nouvelle approche du financement de l'innovation dans le domaine de la fusion par l'UE ; et (2) en tant que démonstration pilote du type de projets qui peuvent également être financés dans le cadre du CPEP.
- Le fait de commencer par un nombre limité de projets pilotes permettra également à F4E de s'organiser pour sélectionner et gérer ces programmes de manière efficace et efficiente, ce qui peut nécessiter un processus d'apprentissage par rapport aux marchés existants pour ITER.
- Pour garantir une approche de partenariat, certaines conditions doivent être attachées au financement, notamment la nécessité d'avoir au moins un partenaire de recherche dans un partenariat d'innovation et la nécessité d'une contribution (en nature ou financière) au coût total du projet de la part de l'industrie et des partenaires de recherche, c'est-à-dire qu'il ne s'agit pas d'une subvention ou d'un marché public.
- Étant donné que l'accent est mis sur les technologies les plus éloignées du marché et/ou ayant moins d'applications en dehors du secteur de la fusion, il est recommandé que la contribution attendue de l'industrie soit de l'ordre de seulement 10 à 30 % des coûts totaux.
- L'approbation par la CE de cet instrument et l'utilisation des fonds par F4E renforceraient le mandat actuel de F4E (envers DEMO et l'innovation industrielle) et lui permettraient d'avancer en toute confiance.

Créer un Partenariat Européen Co-programmé pour l'innovation en matière de fusion dans le cadre d'Euratom, qui devrait démarrer dès que possible, idéalement au cours du programme de travail 2025-2027, et au moins à partir de la prochaine période du CFP en 2028. Cela compléterait l'approche du partenariat d'innovation F4E, tout en se distinguant par les caractéristiques suivantes :

- Il devrait cibler un budget de plusieurs dizaines de millions par an, par exemple entre 30 et 100 millions d'euros, des budgets potentiellement plus petits pourraient être envisagés au cours des premières années, au fur et à mesure du démarrage du programme. Des budgets plus importants seront très probablement nécessaires à l'avenir pour couvrir les coûts du développement et de la démonstration des technologies à grande échelle.

- Le Programme Stratégique de Recherche et d'Innovation (SRIA) devrait cibler les technologies clés dans leur ensemble, mais en mettant l'accent sur celles qui présentent des possibilités commerciales ou des applications plus claires à court et moyen terme (c'est-à-dire dans les 5 à 8 ans) en dehors du secteur de la fusion. La raison repose sur la nécessité de ces possibilités commerciales pour attirer l'industrie et les contributions de contrepartie nécessaires (à hauteur de 50 %), ainsi que sur la cohérence avec l'instrument F4E proposé. Parmi les exemples à privilégier figurent : les technologies de fabrication d'aimants supraconducteurs, les systèmes de chauffage (gyrotrons, injecteurs à faisceau neutre), les systèmes de manipulation à distance.
- Nous recommandons une répartition du financement d'environ 75/25, avec 75 % réservés aux technologies clés (KET) pertinentes pour DEMO, et 25 % réservés à d'autres approches de fusion, permettant d'investir dans des technologies pertinentes pour la fusion inertielle, la fusion magnéto-inertielle ou d'autres approches de confinement magnétique. Le fait de réserver cette petite partie permet aux entreprises de l'UE ayant des approches à haut risque et à fort potentiel de passer à l'échelle supérieure.
- Les activités pour le segment principal (75 %) devraient être axées sur des projets de développement et de démonstration. Pour le segment des autres approches (25 %), une plus grande variété d'activités de recherche pourrait être prévue, y compris, par exemple, le financement de chèques d'innovation de type INFUSE permettant aux entreprises d'acheter du temps, de l'expertise et des connaissances auprès des institutions de recherche de l'UE.
- Le volet DEMO devrait également contribuer à positionner l'industrie européenne dans les chaînes d'approvisionnement mondiales pour toutes les approches de fusion basées sur le confinement magnétique, de sorte que l'industrie européenne puisse également être un fournisseur de premier plan de dispositifs de fusion publics ou privés aux États-Unis, au Royaume-Uni, en Chine, au Japon ou ailleurs.
- On s'attendrait à ce que les consortiums qui répondent aux appels lancés dans le cadre de ce PPP sur la fusion soient dirigés par l'industrie, incluant des partenaires de recherche. Des start-ups pourraient également être envisagées comme chefs de file des consortiums, non seulement pour le segment de financement des approches alternatives, mais aussi pour le segment traditionel du confinement magnétique.
- Les CPEP doivent généralement être limités dans le temps, conformément aux périodes du cadre financier pluriannuel (CFP). Cependant, la nécessité d'un PPP sur la fusion pourrait s'étendre jusqu'à la construction et l'exploitation d'une centrale de demonstration électrique à fusion, c'est-à-dire éventuellement dans les années 2040 et 2050. Il convient d'en tenir compte dès la mise en oeuvre du PPP, notamment lors de l'élaboration de l'Agenda Stratégique pour la Recherche et l'Innovation.
- Les détails sur la gouvernance, le processus et les règles de propriété intellectuelle du CPEP sont traitées séparément.

Assurer un minimum de financement disponible pour la fusion dans l'EIT-CCI InnoEnergy : l'objectif principal est de garantir un certain niveau de financement de démarrage pour les start-ups de fusion dans l'UE, cela devrait inclure non seulement les entreprises qui poursuivent leurs propres approches de fusion, mais aussi les PME dans la chaîne d'approvisionnement.

À l'avenir, d'autres instruments pourraient également devenir pertinents : le Fonds pour l'innovation ('Innovation Fund'), Breakthrough Energy Catalyst, la BEI et d'autres fonds pourraient tous devenir plus intéressants à l'avenir, à mesure que le TRL pour la fusion et les technologies clés (KET) augmentent. Dans le contexte de DEMO, il pourrait également s'avérer intéressant d'explorer la création d'une société ou d'un partenariat spécifique au sein d'Euratom pour financer la construction, mais il est peu probable que cela soit pertinent avant 2030.

Note : il est important de mentionner que l'approche PPP proposée est développée sur la base qu'elle n'a pas d'impact sur le travail en cours d'EUROfusion ni sur le travail de F4E sur ITER, BA, IFMIF-DONES, c'est-à-dire que tout PPP serait supplémentaire. Par conséquent, les travaux existants menés par EUROfusion devraient se poursuivre sans changement, y compris les travaux scientifiques avec les TRL les plus bas pour les technologies clés, ainsi que les premiers travaux de conception et d'élaboration pour DEMO. Le principal groupe cible du financement d'EUROfusion est la communauté de la recherche, mais l'industrie a également une légère implication, en tant que fournisseur, par exemple par le biais de contrats-cadres visant à soutenir le concept et l'élaboration de DEMO. Le financement d'EUROfusion est également essentiel pour continuer à développer et former un vivier de personnel pour le secteur de la fusion dans son ensemble.

Le chapitre 5 de ce rapport fournit des détails plus spécifiques sur la signification de ces recommandations pour chaque type de partie prenante et DEMO.

Actions recommandées pour la CE

Quelques mesures clés doivent être prises et un rôle pour la CE dans chacune d'elles :

Établir le soutien politique pour un CPEP fusion. Nous comprenons que si la décision d'aller de l'avant est prise, le projet sera créé sous les auspices d'Euratom et n'aura donc pas besoin de passer par le processus actuel de sélection des partenariats candidats d'Horizon Europe. Toutefois, les services de la CE devront prendre les dispositions nécessaires pour garantir qu'un CPEP (dans le cadre d'Euratom) puisse démarrer le plus rapidement possible au cours des prochaines années.

Communiquer avec l'industrie et soutenir la création d'une organisation européenne représentative du CPEP. La CE devrait s'entretenir avec l'industrie afin de l'inciter à s'organiser de manière à ce qu'elle soit compatible avec un CPEP. Une **Action de Coordination et de Soutien** pourrait soutenir l'industrie et la communauté de la recherche dans le processus de création d'une telle organisation. Cependant, cela pourrait ralentir le processus et une alternative plus rapide sans soutien pourrait être également promue auprès des parties prenantes. Il conviendrait d'utiliser le Fusion Industry Innovation Forum (FIIF) et la Fusion Industry Association (FIA), ainsi que F4E et ses réseaux d'agents de liaison industriels, avec également la participation d'EUROfusion. La CE n'a pas besoin d'être directement impliquée dans la formation d'une association professionnelle européenne de l'industrie de la fusion (distincte de l'organisation chargée de gérer le CPEP) dans le cadre de ce processus, mais cela pourrait constituer un résultat supplémentaire bienvenu.

Proposer un Agenda Stratégique de Recherche et d'Innovation (SRIA) et travailler avec les parties prenantes pour le finaliser. Faisant un pas vers une stratégie européenne d'innovation en matière de fusion (voir ci-dessous), l'UE devrait proposer un SRIA qui définit les principaux domaines d'intérêt et les étapes à franchir et souligne également la manière dont le CPEP devrait contribuer à accélérer l'innovation dans la fusion et à soutenir l'industrie. Elle doit également être cohérente avec les autres instruments et activités en cours. Suite au processus décrit au point 4.3.1, le SRIA devrait être discuté et affiné avec les parties prenantes de l'industrie et de la recherche du CPEP, afin de le détailler et d'affiner davantage vers un SRIA final convenu, cela pourrait faire partie de l'ACS mentionnée ci-dessus.

Apporter un soutien politique aux partenariats d'innovation F4E. Bien que F4E ait déjà un mandat pour travailler sur DEMO, des sensibilités pourraient apparaitre quant à la redéfinition des priorités des budgets de F4E vers des activités orientées sur DEMO, en particulier dans le contexte des retards d'ITER. Recevoir le soutien de la CE pour emprunter cette voie encouragerait F4E à agir. La CE devrait revoir le Plan de Développement Technologique (PDT) de F4E pour garantir la cohérence entre des instruments PPP proposés.

Établir une voie d'accès aux start-ups au financement de démarrage dans l'EIT-CCI InnoEnergy. Dans le cadre de l'EIT-CCI InnoEnergy ou d'un mécanisme similaire, la CE devrait vérifier et, si possible, garantir qu'un financement suffisant soit disponible pour investir dans les start-ups de fusion dans l'UE. Les start-ups seraient également éligibles pour participer aux instruments CPEP et F4E proposés.

Élaborer une stratégie d'innovation européenne pour la fusion. Une vision ou une stratégie globale de fusion au sein de l'UE était une demande claire des parties prenantes tout au long des travaux.

Même si une stratégie complète n'est peut-être pas réalisable à ce stade, il faut au moins une stratégie d'innovation de fusion qui définit et relie les objectifs d'innovation à atteindre, les moyens à mettre en œuvre et les instruments à utiliser pour chacun. Cette stratégie devrait également prendre en compte les programmes nationaux. Une stratégie européenne d'innovation en matière de fusion contribuera à créer un paysage positif et cohérent pour l'innovation dans ce domaine dans l'UE et définira également le rôle des principales parties prenantes et chacun des instruments à utiliser.

1 INTRODUCTION

1.1 Background

Fusion energy is entering a period of rapid development with increased public and private finance flowing into the sector globally and fusion initiatives, both public and private, marking significant scientific and technical advancements in the last few years. Significant progress in the last few years includes the records set at: the Joint European Torus (JET) with record power generation and sustained fusion achieved in 2021; and the National Ignition Facility (NIF) in the United States which in December 2022 achieved net energy gain (at the plasma boundary), delivering 2.05 MJ of energy to the target and registering 3.15 MJ of fusion energy output. Furthermore, major achievements in steady state and/or high-temperature operation of tokamaks in China (EAST) and Korea (K-STAR) are pushing forward fusion knowledge.

Whilst JET is undertaking its final experimental campaigns in 2023 before decommissioning, the other devices remain active and new devices and experimental campaigns begin around the world. Of particular interest for the EU are the experiments at the Wendelstein W7-X stellarator in Germany, which has started new campaigns after a round of upgrades, and the final commissioning of the JT-60SA tokamak built in Japan within the Broader Approach collaboration between the EU and Japan. In the US, repairs to the NSTX-U tokamak at the Princeton Plasma Physics Laboratory are expected to be completed and further research will begin soon.

Alongside these developments, the ITER project continues to make progress towards first plasma as construction and assembly continue in France. Whilst some delays to first plasma are expected due to the COVID pandemic and other difficulties, the revised timeline is not yet public and slippage of several years is expected.

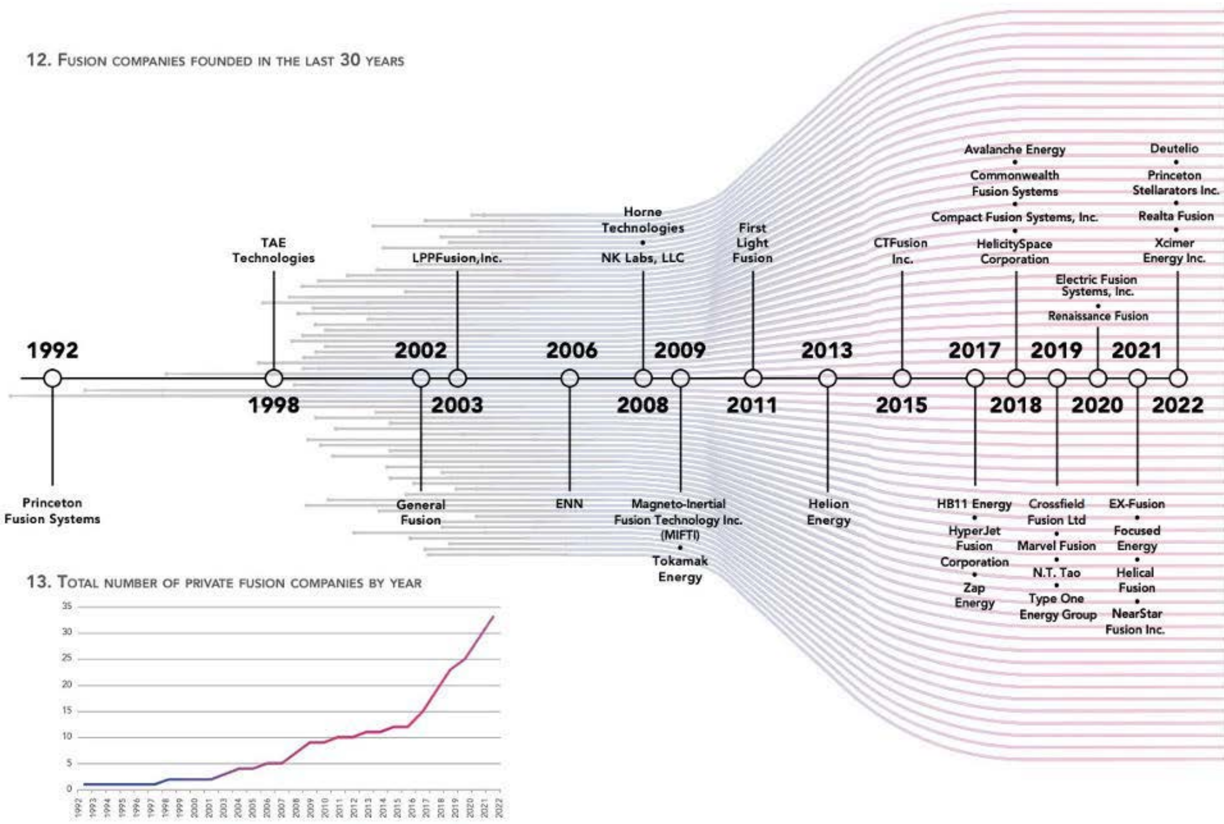
The work at JET and W-7X, the joint development and operation of JT-60SA, hosting and making the major contribution to ITER highlight the major role that European researchers and industry are playing in fusion energy development. Furthermore, these highlights only represent a part of the significant work being carried out, with EUROfusion coordinating work by national laboratories across Europe, each contributing to scientific research in fusion. This puts Europe at the forefront of public-funded fusion research and development.

The private fusion sector has also accelerated in the last years, significantly expanding its funding and progress. Eye-catching headlines from start-ups in the sector include: achieving high temperatures; developing high-field superconducting magnets (Commonwealth Fusion Systems, Tokamak Energy); achieving first steps towards potential proton-boron fusion (TAE Technologies)[1]; and even signing power purchase agreements to deliver fusion electricity already in 2028 (Helion Energy)[2]. Leading firms in the sector are working on constructing and assembling their next fusion devices which aim to further prove the validity of the concepts. Whilst it is unlikely that all will succeed, some may make important gains. However, those at the forefront in the private fusion sector are primarily US- or UK-based, with European firms joining more recently. The start-ups emerging in Europe include Renaissance Fusion in France; Gauss Fusion, Proxima Fusion, Focused Energy and Marvel Fusion in Germany; Deutelio in Italy; and Novatron Fusion in Sweden. The Figure 1-1 below shows how the start-up sector has expanded rapidly over the last few years.

1 https://tae.com/tae-technologies-and-japans-national-institute-for-fusion-science-nifs-begin-joint-experiments-with-new-fusion-fuel/

2 https://www.helionenergy.com/articles/helion-announces-worlds-first-fusion-ppa-with-microsoft/

Figure 1-1 Fusion companies founded in the last 30 years[3]



Europe has a leading position but risks are emerging

All in all, Europe has a leading role in fusion energy scientific research for mainstream magnetic confinement approaches, with its industry at the forefront of producing components, and in the construction and assembly of tokamaks and stellarators. This has provided cutting-edge experience and knowledge in manufacturing and engineering for fusion, which places European industry in pole position to develop its DEMO pilot power plant, and for a central role in a future supply chain for fusion.

However, there are risks to this leading position, both from well-funded public programmes in the US, the UK, China and elsewhere, and from the private start-ups in the US and the UK. The risk is that these initiatives develop their own non-European supply chains, with companies in these countries providing the construction, assembly, manufacturing and engineering expertise needed. There is also a risk that alternatives to magnetic confinement approaches could be successful. This could sideline European research and industry, squandering or making irrelevant the leading position currently held in magnetic confinement-based fusion. With a potential supply chain opportunity estimated to increase to around EUR 7 billion per year as the industry grows, and potentially into the trillions as the full commercial maturity is reached[4], it is crucial for Europe to remain competitive. Furthermore, lack of support can lead to firms moving investments to the US – with the example of Marvel Fusion investing $150 million in the US, whilst lamenting the lack of national and EU funding for fusion[5].

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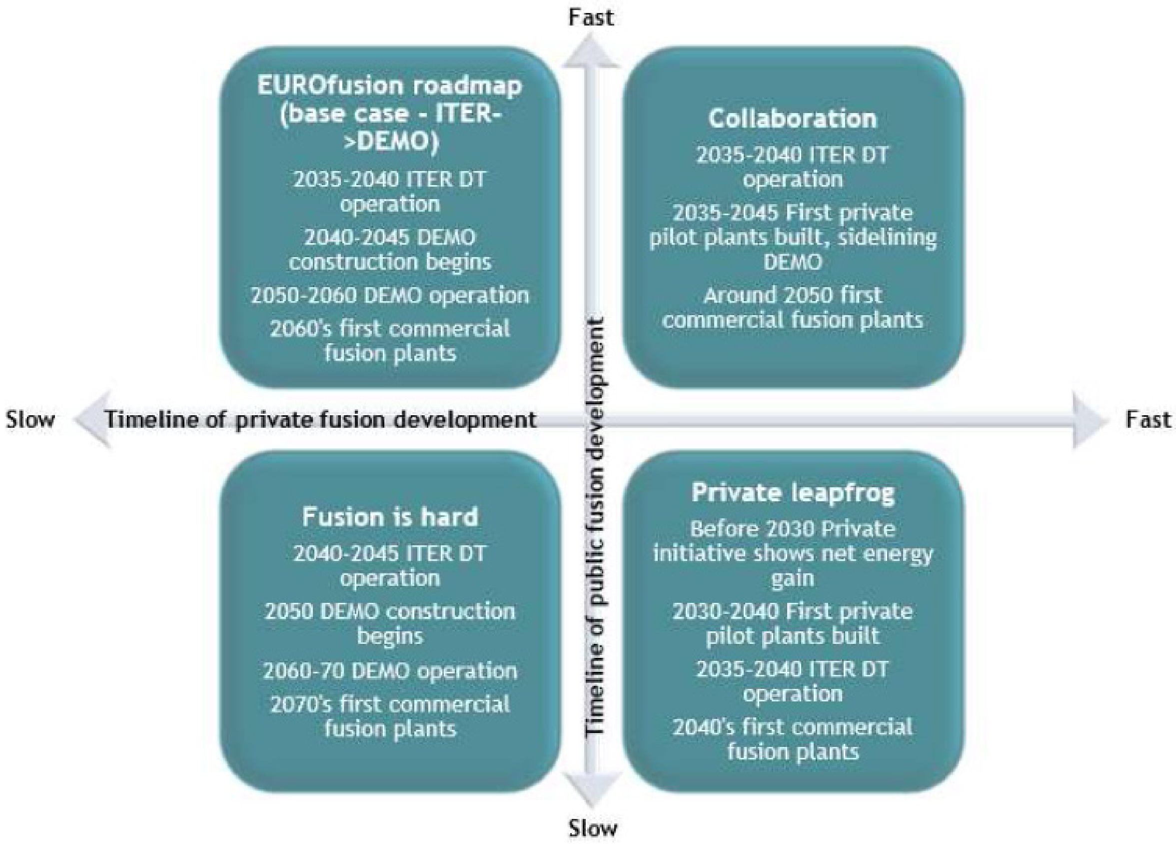
3 https://workweek.com/2023/06/04/early-stage-fusion-gets-even-hotter/ original source: FIA 2022 Report

4 FIA (2023) The Fusion Industry Supply Chain: Opportunities and challenges

5 https://www.cleanenergywire.org/news/german-start-marvel-fusion-invests-us-laments-lack-support-europe

Potential scenarios of fusion development were explored in a fusion foresight study[6], prepared previously to this study. This study set out four likely scenarios for fusion energy development (reproduced below), with attention to the likely timelines and risks for Europe.



Maintaining European leadership and competitiveness – a role for public-private partnerships?

The foresight study made various recommendations for the EU to maintain its strong position in the fusion sector. Amongst them was the consideration to create a public-private partnership (PPP) scheme. This recommendation was based on the observed success of other schemes, particularly of ARPA-E and INFUSE in the US, which have helped to develop the start-up ecosystem in the US and to unlock knowledge held by publicly funded research for commercial applications. In the US, support for fusion has accelerated further in the last year, supported by the Bold Decadal Vision policy, additional public funding for fusion and the creation of a new PPP Milestone-based Program for fusion. Work in the UK to develop the STEP demonstration fusion plant is also utilising PPP schemes to involve industry from the supply chain in the conceptualisation, design and innovation necessary to move forward. The EU is also seeing success in other emerging energy fields such as hydrogen and batteries using public-private partnerships to support industry development.

For the EU, the considerations relevant for a possible PPP scheme for fusion are multiple and include:

[6] Trinomics, for the European Commission (2022) Foresight study on the worldwide developments in advancing fusion energy, including the small scale private initiatives, available at: https://op.europa.eu/o/opportal-service/download-handler?identifier=83bc3ecd-b19c-11ed-8912-01aa75ed71a1&format=PDF&language=en&productionSystem=cellar

- Taking the next steps in the design and development of DEMO for which increased industrial involvement (compared to ITER) is seen as highly desirable to increase the speed and efficiency of the process.
- Supporting industry and research institutions to work more closely together to continue innovation and technology transfer and avoid that knowledge and know-how from involvement in the ITER supply chain is not lost.
- Improving support to assist start-ups in the EU to also create a vibrant private fusion industry in Europe to compete with those elsewhere.
- Finding a stable and predictable framework for European industry and research which fits with the legal and financial rules and constraints, and can support continued innovation and competitiveness of the European fusion sector.
- Securing a well-qualified workforce in the fusion sector.

1.2 Objectives

The goals of this study therefore include:

- Analysing PPP schemes around the world, both within and outside fusion energy, to understand their key characteristics, strengths and weaknesses – and what can be learnt to inform an EU scheme.
- Using the analysis of PPP schemes to set out the key design features of an EU PPP scheme for fusion energy which fits with the broader strategic, organisational, legal and financial context.
- Additionally, mapping and identifying stakeholders in the European fusion sector that are keen to engage in a PPP and further innovation in the field of fusion.

1.3 Methodology and approach

1.3.1 Desk review

The analysis presented in the following chapters is supported by an extensive desk review of materials related to the existing PPP schemes and other information relevant to the design of an EU PPP scheme. Specific references are footnoted in the text.

1.3.2 Interviews

As part of this work, the core team held structured interviews with 35 key stakeholders in the fusion sector and associates to the team held many more discussions with other stakeholders through their networks.

The interviews are distributed across multiple stakeholder types, both public and private, fusion and non-fusion with the approximate breakdown provided below:

- 17 - Fusion industry and supply chain
- 6 - National labs (EU and global)
- 5 - Fusion start-ups
- 5 - Other stakeholders (FIA, investors, F4E)
- 2 - PPP schemes (fusion and non-fusion)

The stakeholders who confirmed their participation in the interview received an interview guide with a list of questions tailored to their stakeholder type prior to the interview. An example of this can be seen in Annex A.

1.3.3 Workshop

A stakeholder workshop was held on Tuesday 6th June, from 10h00 to 16h30 C.E.T at Albert Borschette, Brussels. The objective of this workshop was to:

- Present research on options for a PPP scheme for fusion energy, and exchange with the concerned stakeholders about the most appropriate design for an EU PPP. The outcome will inform European Commission decision making and the possible creation of a new PPP programme as part of the development of the new EU fusion policy.

The targeted stakeholders included representatives of the fusion supply chain covering fusion, nuclear, manufacturing of key components for fusion (all technology routes), engineering, construction, energy, and investing; national laboratories and research centers active in fusion; fusion start-ups; and umbrella organisations (Fusion Industry Association, EUROfusion, F4E and F4E industrial liaison officers).

Around 60 people attended the event in person, and a further 20 attended online. The workshop agenda is presented Annex B.

1.3.4 Validation focus groups

The work also includes the use of focus groups. Meetings with 4 groups were held (online) in September 2023, the first two groups discussing the draft final report of the work, and the final two groups – a revised proposal based on feedback from the first. The groups hosted 3-8 stakeholders, both public and private, and presented key aspects of the proposed design for in-depth discussion and validation.

2 ANALYSIS OF PUBLIC-PRIVATE PARTNERSHIPS RELEVANT FOR FUSION

2.1 Background and objectives

2.1.1 Public-private partnerships in the literature

In this subsection we provide a concise overview of the literature on PPP schemes, focusing on the elements relevant for this analysis concerning governance, funding and risk management evaluations, as well as available information on PPP for innovation. The objective is to extract the key features and trends from the academic literature out of these theoretical considerations.

Public-private partnerships are a form of **cooperative institutional arrangements** between public and private sector actors, widely applied across developed economies[7]. While presenting themselves in varying forms and contexts, PPPs generally involve a durable cooperation between private and public actors in which they jointly develop products and services to **share risks, costs, benefits and resources**[8]. Often connected to large infrastructure projects of high public relevance, PPPs are arrangements for cooperation that establish a new organizational unit. In the context of infrastructure development and management, PPPs are also seen as financial models where the public sector makes use of private finance capital to drive large-scale projects[9]. The basic benefit of PPPs derives from the combination of the specific qualities of the public and private sides. Contractual arrangements present various forms, which the literature regroups in BOT (build-own-transfer) and BOOT (build-own-operate-transfer) contracts[10]. Therefore, while referring in practice to a loose concept, PPPs comprise two essential design features: the way public and private actors engage financially in the PPP; the degree of interconnectedness between public and private actors.

When evaluating PPPs, a recurring element concerns the **management and sharing of risk between parties.** From an economic efficiency perspective, risks are optimally shared between the partners, assigned either to the state, the private party or a third-party insurer[11]. Although no set method exists to share risks, the literature suggests that most of them can be transferred to the private sector, while the state retains the management of “acts of nature” (i.e. natural disasters and unforeseeable events of the sort) and the fiscal risks. The latter refer to weaknesses in the legal and institutional frameworks or in the design of the policies that affect the project. From the viewpoint of the private operator, these are risks pertinent to regulatory uncertainty and, generally, risks associated with political instabilities and unexpected changes in regulatory commitment or support to a given project or set of objectives[12]. Other types of risks stem from asymmetry of information between the private and public entities. By signing a partnership contract, the public authority delegates responsibility to the private sector, **adding a set of risks**. In this context, the private sector is usually better placed as it generally has more information on its own ability to carry out the tasks and the nature of its actions, as well as the characteristics of the project – given that the private entity usually has a better understanding of the sector it operates in[13].

In the **European PPP environment**, risk can be defined as the “unexpected variation in value”. In this context, risk management involves identifying the risks, assessing their potential impacts (in value or

7 De Palma et al. (2012), Grimsey, Lewis (2000)
8 Van Ham and Koppenjan (2001)
9 Carbonara et al. (2013)
10 Carbonara, Pellegrino (2020)
11 Marques, Berg (2012)
12 Heydari et al. (2020)
13 Warsen et al. (2019)

cost terms), and identifying a strategy to best manage them; with PPPs, this refers specifically to the risks between the contracting authority and the project company. Of course, as the project unfolds, new risks emerge or change, which requires the continuous monitoring throughout a project cycle. For EU partnerships, a streamlined process was laid out by the European Investment Bank[14] for the management of risk, as follows:

- The assessment of value for money and, therefore, the choice of whether or not to use a PPP delivery model;
- The preparation and terms of the PPP contract, including the development of the payment mechanism, early termination and variation provisions;
- The assessment of expected lifecycle costs and, hence, affordability and budgeting for the PPP project (including the costs of further forms of government support, such as guarantees);
- The assessment of the bankability of the PPP project and the capacity of the private sector to deliver the project;
- The statistical treatment of a PPP project in line with Eurostat guidelines.

PPP for innovation

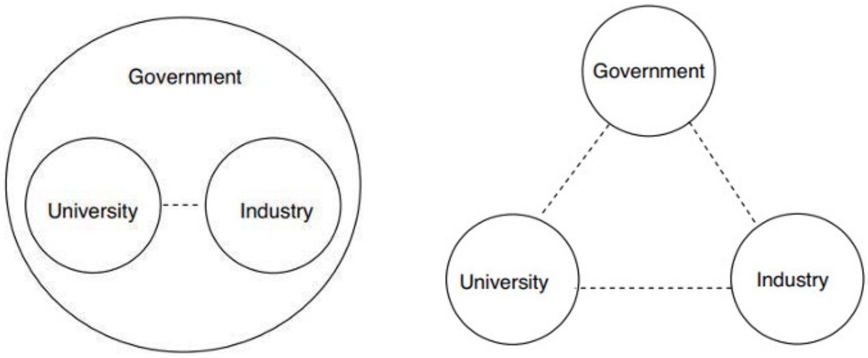
While PPP are primarily studied in the context of large infrastructural development, there has been a surge in such arrangements to address and drive innovation. The concept of **public-private partnership in innovation** was formulated in 2002 by the OECD Committee for Science and Technology Policy as follows: "any formal relationship or agreement for a fixed or infinite period of time, between public and private actors, in which both sides cooperate in the decision making and priority setting process and co-invest limited resources, such as money, personnel, equipment and information, to achieve specific goals in a specific area of science, technology and innovation"[15]. In this context, the aim of a PPP is to develop scientific and technological potential and the formation of a competitive industry. Within these systems, a new distribution of roles emerges: the public authority establishes and guarantees the institutional environment for the activities of all the participants, sets the "rules of the game", and promotes the production of fundamental knowledge through public research centres, labs and universities that provide scientific data, methodologies and expertise; in turn, industry and business create a technology through research and development, and materialise these scientific ideas. Some authors in the field highlight the importance and transformative role of the public investments in these partnerships, i.e. that the state is often more willing to spend in high-risk areas than private firms or capital, and that in these areas innovation can hardly happen without strong public investment[16].

As this particular model of public-private partnership emerged and flourished, the theoretical concept of "**Triple Helix"** was developed to capture this specific set-up[17]. A Triple Helix regime starts with a university, industry and government entering into a reciprocal relationship, where each enhance the performance of the other. By first providing their expertise and fulfilling their own purpose, the model theorizes an internal transformation, whereby actors influence and improve each other's tasks, leading to a virtuous cycle of "innovation in innovation"[18]. Therefore, the Triple Helix results in bilateral interactions evolving into trilateral interactions between university, industry and government, adding to the complexity of the regime. The literature distinguishes two major variations in this model: a **"statist model"**, where government has some level of control over academia and industry, and a **"laissez-faire model"** with

[14] EIB, EPEC PPP Guide. Available at: https://www.eib.org/en/readonline-publications/epec-ppp-guide-welcome
[15] UNECE (2008)
[16] Mazzucato, M. (2015) The Entrepreneurial State
[17] Etzkowitz, H., & Zhou, C. (2017). The triple helix: University–industry–government innovation and entrepreneurship. Routledge.
[18] Ibid.

university, industry and government separate from each other, interacting within strong boundaries (Figure 2-1).

Figure 2-1 Statist model (left-hand side) and laissez-faire model (right-hand side)



2.2 Analysis of existing public-private partnerships

2.2.1 Selected partnerships

The project team compiled a mapping of PPP models with the aim of providing a comprehensive sample of existing relevant schemes, across the EU and globally. A number of (non-fusion) programmes at EU level, funded under the Horizon Europe Partnerships 2021-2024, were selected for their differing structures, whole value chain coverage and for their technological component. Programmes in the US and the UK were also selected. Below is the list of PPPs identified as part of this task. See Annex C of this report (separate file) for the complete list of partnership programmes and their description.

Table 2-1 List of selected PPP schemes

Classification	PPP Name	Link with fusion (yes/no)
EU Institutionalised Partnership	The Clean Hydrogen Partnership	No
	The European High Performance Computing Joint Undertaking (EuroHPC JU)	No
	Key Digital Technologies	No
EU Co-programmed partnership	Batt4EU (BEPA)	No
	European Partnership for Clean Steel – Low Carbon Steelmaking.	No
	European Partnership for Connected, Cooperative and Automated Mobility	No
	Europe's Rail Joint Undertaking	No
EU Co-funded partnership	Clean Energy Transition (CET)	No

Classification	PPP Name	Link with fusion (yes/no)
Other types of PPPs in Europe	Breakthrough Energy Catalyst Europe	No
	European Institute of Innovation and Technology (EIT-KIC InnoEnergy)	Yes
	(DE) SPRIN-D – Pulsed Light Technologies	Yes
US PPP with no link to fusion	Advanced Reactor Demonstration Programme (ARDP)	No
	NASA Commercial Orbital Transportation Services (COTS)	No
US PPPs targeting fusion	INFUSE - Innovation Network for Fusion Energy	Yes
	SBIR/STTR	Yes
	Milestone-Based Fusion Development Programme	Yes
US ARPA-E programme	ARPA-E ALPHA	Yes
	ARPA-E BETHE	Yes
	ARPA-E/FES GAMOW	Yes
	ARPA-E OPEN	Yes
	ARPA-E Exploratory Topic D	Yes
UKAEA programme	UKAEA Spherical Tokamak for Energy Production (STEP)	Yes
	UKAEA Fusion Industry Programme Equity Scheme	Yes
	UKAEA Fusion Industry Programme Voucher Scheme	Yes
	Small Business Research Initiative (SBRI) - UKAEA Fusion Industry Programme Challenge scheme (operating under SBRI)	Yes

2.2.2 Analytical framework

The project team developed a set of criteria to systematically analyse the PPP models, based on the review of the literature and identifying the most critical elements mentioned as part of their analysis of partnerships. The set of criteria comprises indicators and information about the programmes, their governance and objectives, the functioning and rules, and current approaches used for their evaluation (if any). The proposed analytical framework comprises the following criteria:

Table 2-2 Analytical framework to analyse the PPP schemes

Macro category of assessment	Specific analytical criteria
Governance and legal characteristics	Objectives of the partnership Management of the partnership, roles and responsibilities Content of calls for proposals Rules on Intellectual Property rights
Funding allocation	Source & type of funding Decisions to allocate resources and rules on duration
Available assessment metrics	KPI monitoring and reporting Risk management Other sources on perceived progress

2.3 Analysis of the selected schemes

In this section, we provide a comprehensive overview of the selected schemes. We follow the analytical framework developed within the previous section, to shed light on the schemes' key-characteristics. Ultimately, this serves the aim of comparing across this large number of initiatives, to identify patterns, commonalities and differences. While mentions to individual programmes are made to highlight remarkable features, the classification in Table 2-1 is used for the sake of clarity.

2.3.1 Governance and legal characteristics

Objectives of the partnership

As a general aim, all partnerships analysed aim to **bring academia, business and governments together to foster innovation** and provide companies with access to the technical and financial support necessary to progress new or advanced technologies - recognising that innovation varies greatly from research to traditional commercial activities, and thus requires different parties involved. Common features of all programmes are **de-risking and removing barriers** to innovation and commercialisation. They do this by providing **public finance instruments**, as well as access to **research labs and facilities**, either on the EU or the national level. Their objective is either to demonstrate or commercialise a specific technology (e.g. fuel cells, energy storage or fusion-related components), or to look into low-TRL[19] level innovation that could result in a breakthrough – the ultimate goal being the delivery of some form of infrastructure benefiting the wider public (including enabling technologies, parts or the whole asset).

[19] We use the technological readiness level framework in multiple instances in this report, the levels can be summarised as:
1. Initial idea: basic principles have been defined
2. Application formulated: concept and application of solution have been formulated
3. Concept needs validation: solution needs to be prototyped and applied
4. Early prototype: prototype proven in test conditions
5. Large prototype: components proven in conditions to be deployed
6. Full prototype at scale: prototype proven at scale in conditions to be deployed
7. Pre-commercial demonstration: solution working in expected conditions
8. First-of-a-kind commercial: commercial demonstration, full-scale deployment in final form
9. Commercial operation in relevant environment: solution is commercially available, needs evolutionary improvement to stay competitive
10. Integration at scale: solution is commercial but needs further integration efforts
11. Proof of stability: predictable growth

The analysed PPPs thus often target different TRL levels (ranging from low maturity (3) to high (7-8)), and support versatile concepts vs. specific technologies (high-performance superconductors, stellarators, multi-application laser systems, battery storage, solar photovoltaics, etc).

Among the PPP schemes analysed, most EU-wide programmes (whether institutionalised, co-programmed or co-funded) advocate for the need for **Europe's competitive leadership**. They aim to foster European expertise and world-class innovation systems in order **to make the bloc a world leader in key enabling technologies**, while adhering to current energy and climate goals, notably the 2050 climate neutrality target. Some, like the CET partnership, have a transnational focus and aim to **introduce EU solutions to global value chain**.

Some **fusion-focused US programmes**, including ARDP and ARPA-E programmes specifically target those high-maturity options that have the potential to become **cost effective/low-cost** solutions, to make them commercially viable while also safe to construct and operate. At the same time ARPA-E also invests in low maturity, riskier projects with potentially high impact. It is also worth highlighting the Milestone-based Fusion Development Program which requires companies to meet major technical and commercialization milestones toward the successful design of a fusion pilot plant to unlock funding, in order to better motivate them in bringing fusion towards technical and commercial viability.

A lesson learned from the NASA COTS program success was the need for a break from legacy policies or processes that remain from earlier initiatives (e.g. in fusion in the EU this could be from F4E, EUROfusion, ITER). The objectives of a new scheme should not be pre-determined by previous work. NASA advises that the new organization, embarking on a new initiative with non-traditional processes must be treated as an independent, stand-alone entity, which implies establishing a new culture and goals of its own.

Management of the partnership, roles and responsibilities

Given the nature of PPPs, there is a wide variety of actors involved in the programmes with different managerial responsibilities and roles in the partnership structure. The PPP schemes analysed normally consist of all, or most of the below listed organisational bodies:

- **A governing body (Board):** main decision-making body, responsible for the strategic orientation and the working programme, ideally with a diverse membership from public and/or private organisations involved in the PPP
- **An executive body (a Director or an executive group):** responsible for implementing the partnership strategy, and choosing members of the governing body
- **A General Assembly:** consisting of all members, having an advisory role and reflecting on the overall direction of the partnership's activities, ensuring open and transparent discussion on the implementation process of the partnership's strategy
- **Advisory board:** consisting of industrial and/or scientific experts to be consulted

The level and depth of involvement, and thus the influence of public and private actors in the analysed partnerships, varies by PPP, with some having a more public-heavy management than others.

In the PPPs administered at the EU level, it is common to have multiple European Commission Directorate Generals (DG) represented in the Governing Board. At **EuroHPC-JU,** for example, which is an institutionalised partnership, the Governing Board is composed of representatives of the EU and Participating States, where each MS appoints one representative to the Governing Board. Here, users and technology suppliers are a part of the industrial and scientific advisory board. This setup, although often justified by the proportion of EU funding involved, results in a **bigger role for the public actors** in governance, which might not fully reflect the priorities of the business communities which are supposed to implement the high-level strategies on the ground in their respective fields. US ARPA-E programmes for fusion are exclusively led by government offices as well.

In a more diverse model (as seen in the EU Partnership for Clean Steel, as well as the European Partnership for Connected, Cooperative and Automated Mobility) the public side of the Board (i.e. the European Commission and its various DGs) is balanced out with similar numbers of industry representatives/ officials from private companies. The public side ensures coherence and synergies with the European policy and R&I landscape, while the private component of the Board will represent the technical needs of companies from the Partnership and their respective proposals for the work programme, as well as the report on the progress of R&I activities and their alignment with the objectives of the Partnership. Ideally, in this way, decisions in the Board are based on consensus that aligns with market realities of the sector.

As a third variation, e.g. in the **Clean Hydrogen Partnership** (also an EU institutionalised partnership), the industry grouping has a bigger representation in the Board than EU institutions, and has an industry-led implementation structure, with the Board supervising the executive body' activities. At **Batt4EU**, the Batteries European Partnership Association (BEPA), a non-profit association representing the private partners (via BEPA's Association Delegation), has more private representatives in the Board, too.

The following table gives an overview of what the main stakeholder types can bring to a PPP.

Table 2-3 Added value of stakeholders in a PPP

Public actors	Private actors (companies)
Laboratories: provision of complex and costly systems for testing / research and testing facilities and capabilities, computing models, research staff, IP **EU and/or governments:** strategic orientation and policy objectives, coordination of large-scale initiatives, funding(grants/awards), public procurement and contracting , international network and liaison	**Industry (supply chain, start-ups):** Machinery development, integrated design, manufacturing facilities, industrial know-how, product design and market knowledge, other IP, commercial focus, business network, private investment

Turning to **fusion-focused PPPs in the US**, we see a less institutionalised and structured relationship between the two contracting entities. For example, with regards to ARPA-E programmes, they consist of ad-hoc created programs by the US Department of Energy to manage granting processes. Each ARPA-E program comprises a milestone programme where the company recipient is tasked to deliver within that program. Funds are released after successfully reaching milestones, which sets these programmes at the intersection of PPPs and funding scheme. In this case, the ARPA-E through the milestone-based funding, retains a significant degree of discretion and influence over the management and development of the projects, as was stressed during the interview process with stakeholders. The same process applies to Milestone-Based Fusion Programme. Calls under Horizon Europe can also use a similar process, including as Research and Innovation Actions, or Innovation Actions.

Content of calls for proposals and communication

Partnerships are often releasing calls (i.e. requests for funding applications) as the basis of innovation projects. These are based on the different work streams that they lead, which are specific to each partnership. These calls can be open to both members and non-members of the Partnerships (as in the case of the **European Partnership for Clean Steel**) provided that they adhere to the general conditions laid down in their respective work programmes and the applicable legislative framework, or can be limited to the members of the PPP. Calls are usually released online and further disseminated by public authorities, and often indicate the desired TRL level to be achieved as a result of the funding.

In case of the German federal **SPRIN-D** programme, no specific calls for proposal (CfP) are released, besides projects having to fulfil general conditions for acceptability and eligibility, constituting "disruptive innovations". Communication material by the partnerships is usually disseminated by a dedicated communications office via their websites (in case they have one), and includes press releases, final research reports, annual progress reports and invites to content-related workshops and conferences.

Rules on Intellectual Property rights

Rules and arrangements regarding intellectual property are generally considered to be one of the primary issues in using PPPs as a policy tool to **promote innovation** and encourage the development of new technologies. Delineating the ownership of a given set of results or of a scientific and technological breakthrough is important to define the risk-reward of the arrangement. Among the PPPs analysed, while the IP tends to be owned by the participants generating them, there are differing rules and criteria applied to these situations.

For instance, among EU **institutionalised partnerships**, there are dispositions for the establishment of joint ownership of results, when these are jointly generated[20]. The joint owners may agree not to continue with joint ownership but decide on an alternative regime, by transferring their ownership shares to a single owner with access rights for the other participants. In the case of subcontractors and buyers, the former holds the ownership of the results, while the buyers have the right to access results on a royalty-free basis for their own use. In the other EU partnership types, the co-programmed and co-funded, information on IP rules is scarce, hinting that these matters are treated within the individual grant agreements.

Among PPPs targeting fusion projects in the US, including **ARPA-E**, the approach tends to be more streamlined. These programmes involve a special type of Government Patent Rights, a royalty-free right to practice invention by or on behalf of the Government. These include specific requirements regarding the manufacturing of the invention in the US. Finally, less details are found for **UKAEA** programmes. The IP rights are understood to remain with the applicant, therefore allowing commercialisation across the UK and internationally.

2.3.2 Funding allocation

Source and type of funding

The source and type of funding is considered a primary factor for enabling a PPP to work on achieving its objectives. They play a crucial role in attaining the necessary resources and enabling tasks to be performed. Among the PPPs analysed, there is a focus on a diverse range of EU PPPs, a few selected EU fusion-related investments and US and UK fusion-focused programs and partnerships.

Under **Horizon Europe**[21], risk bearing varies by instrument type:

- in case of RIAs (Research and Innovation actions) and CSAs (Coordination and support actions), the EU covers up to 100% of the project costs;
- Under Innovation Actions (IA) the EU covers between 30 to 70% of the costs;
- While Co-funded actions (COFUND) and PPPs get multiannual funding for up to 30-70% of their costs.

Among EU **institutionalised partnerships** (see also section 3.3 for further details), whilst the instruments listed above can be used for individual calls, it is required that over the full term of the partnership that EC contributions are at least matched by the partners (industry & research) or Member

[20] The Clean Hydrogen Partnership.

[21] https://rea.ec.europa.eu/horizon-europe-how-apply_en

States (for co-funded partnerships). For example, the Clean Hydrogen Partnership has an equal amount of investment, with both public and private sector members supporting the project with approximately €1 billion each, raising the total budget to a minimum of €2 billion. Alternatively, most of the funding for the European High Performance Computing Joint Undertaking comes from the EU long-term budget, the Multiannual Financial Framework with a contribution of €3 billion. The EU contribution is matched by a similar amount from the participating countries. Additionally, private members are contributing an amount of €900 million, primarily through in-kind contributions.

The notable EU fusion-focused investments that are mentioned below are parts of larger government funds that are focused on investments in disruptive innovations and technologies and could be considered as models for an EU fusion PPP.

First, for the **SPRIN-D**, the German government-based agency's investment in Pulsed Light Technologies (generation of energy from laser-driven fusion), it is their first and only fusion investment so far. After conducting an analysis and evaluation process, the agency has the right to establish project subsidiaries for projects with promising breakthrough potential which are funded with between €4 to €15 million annually by the German Federal Government. Additionally, participants who take part in the agency's innovation contests can receive funding ranging between €500,000 and €3 million. The funding is provided as pre-commercial procurement for research and development services.

Second, in response to a 2022 call for proposals, **EIT KIC Inno Energy** in partnership with Stockholm's KTH Royal Institute of Technology awarded €3 million in a seed round to Swedish fusion startup Novatron Fusion. In a 2023 call, following an EIT agreement, the maximum amount of investment was decided at €2 million per company per year. Additionally, it has been decided that at an aggregated level, each company will need to provide 30% co-funding.

Requiring matching funding from the industry is similar to the basis on which EUROfusion already works, with the EC providing 55% of the funding and 45% provided by the consortium members (via their national governments). These same rules would apply to EUROfusion working with industry, but EUROfusion understands that industry is not yet willing to provide such significant contributions itself.

Among **partnerships targeting fusion programs in the US**, the funding process seems rather streamlined. For instance, a few ARPA-E related programs (ARPA-E Alpha, ARPA-E Bethe) typically require cost-sharing, the degree of which depends on the specific call (Funding Opportunity Announcement). If a project award is made through a Technology Investment Agreements or an "other transaction" agreement, the minimum cost share obligation is 50% of the Total Project Cost[22]. The contributions might be provided in the form of cash or in-kind. Instead, if awarded under a Cooperative Agreement or grant cost share minimums can vary between 5%, 10% or 20% of the project costs, and considering the size of the applicant (small firms are expected to contribute less). In terms of funding size, there is variation depending on the type of programme and number of recipients. For the ARPA-E and FES GAMOW programme, ARPA-E will contribute up to $15 million in funding over a three-year program period, and FES will contribute up to $5 million per year for three years for qualifying technologies. 14 projects have been funded so far for a total of USD 26.5 million, or an average of around USD 1.9 million per project. It is important to note that all ARPA-E related investments are focused on advancing high-potential, high-impact energy technologies that are too immature for private-sector investment. **INFUSE,** requires no less than a 20% cost share from companies[23]. In the **Milestone-based Fusion Development Program** there is a cost sharing agreement, where applicants should provide at least 50% of the funds, while the remaining funds are disbursed in the form of a grant from the U.S. Department of Energy[24]. In the case of **SBIR/STTR**, all government agencies are mandated to set aside 4% of their budgets annually to the

22 Section 4 on cost sharing https://arpa-e.energy.gov/faqs/general-questions

23 https://infuse.ornl.gov/wp-content/uploads/2021/12/FY2022-INFUSE-RFA-Call.pdf

24 https://www.fusionindustryassociation.org/department-of-energy-announces-milestone-public-private-partnership-awards/

SBIR program. The funding is always issued as a grant (100% funded), either as a Phase I ($200,000) or Phase II (of $1 million). There are other phases supported by various agencies, such as a Direct to Phase II grant, or Phase III commercialization grant. However, it is rare for the Department of Energy to issue anything beyond Phase II funding.

Among partnerships targeting fusion programmes in the UK, there are several UKAEA schemes that fall under the Fusion Industry Program, each having specific funding schemes unique to the type of program. As an example, the **UKAEA Fusion Industry Program Equity Scheme** invests in fusion-relevant companies at an early stage and involves equity investments of £50,000 to £300,000. In addition, **t**he **UKAEA Fusion Industry Program Challenge Scheme** which operates under Small Business Research Initiative (SBRI), involves the disbursement of funds through procurement contracts that are launched through Phase I projects, with the selected applicant going on to reach Phase II. Phase I projects can range in size with total costs between £50,000 and £200,000, inclusive of VAT. At Phase II, the funding size is typically around £1 million but can go up to £3 million, depending on available funding. The funds at this stage are provided to develop a prototype and undertake field tests for up to 20 months. The **UKAEA Fusion Industry Program Voucher Scheme**, provides up to £50,000 of specialist support towards understanding facility options and designing viable experiments, followed by free access to the specific UKAEA facilities to run initial experiments. This kind of scheme makes it easier for UK businesses to make use of specialist fusion technical facilities, giving them access to the latest skills and techniques. In all the examples mentioned above, the source of the funds is from UKAEA.

In summary, while the source and funding differ, depending on the type of partnership and its objectives, it remains clear, that across many partnerships, it is **the public sector that drives early-stage investments**, albeit there are certain exceptions. In the case of the EU PPPs, there appears to be an equal amount of investment, with both public and private sector members supporting the partnership, in most cases. However, in the case of the other EU fusion-focused investments, public sector funding is driving the projects, all of which appear to be early-stage investments. When it comes to the US, the funding process is dependent on the type of programme. For instance, the ARPA-E program focuses on advancing high-potential, high-impact energy technologies that are too early for private-sector investment, except for the ARPA-E OPEN program, that has 20% funds coming in from the private sector. Similarly, SBIR related investments are also public sector fuelled early-stage investments. On the contrary, the Milestone-based Fusion Development Program has a cost-sharing agreement where applicants need to provide at least 50% of the funds. The UK fusion-focused programmes and partnerships also appear to be driven by the public sector, where government-based funds are supporting early-stage investments.

Decisions to allocate resources and rules on duration

Whilst for most PPPs there is some information available in the details of calls for proposals, workplan documents and budgetary statements there is much less information on the specific selection and evaluation criteria for decisions.

Across the **EU partnerships** mentioned in this section, the decisions to allocate resources and the rules on duration were not easily accessible, but the calls for proposals and workplans gave some insights. Across partnerships it is indicated that the governing body should approve the launch of calls for proposals, in accordance with the annual work plan. Furthermore, in many cases, the decision to allocate resources is dependent on the extent to which submitted proposals address challenges mentioned in the calls. For instance, in the **Clean Hydrogen Partnership**, the decision to allocate resources is based on the extent to which submissions in the call for proposals address key challenges which encompass different areas of research and innovation (for example, renewable hydrogen production, hydrogen storage and distribution, etc). Additionally, in terms of rules on duration, the financial resources will be continuously allocated during the seven-year period to high TRL projects and demonstrators.

In some of the workplans, there are also specifications as to higher or lower TRLs being a necessary condition for allocating resources. In the case of **Key Digital Technologies Joint Undertaking** (KDT JU), three calls were launched in 2023. The first call for Innovative Actions was focused on higher TRLs and the second call for Research and Innovative Actions was focused on lower TRLs, the third a combination. There are further specifications mentioned within the call where the targeted TRL at the end of the project is expected to be between 3 and 4. Another common element seen across the work plans of partnerships is the selection criteria for proposals with the same score. One such example can be seen in the KDT JU workplan, where proposals that address aspects of the call that have not otherwise been covered by other more highly ranked proposals are given the highest priority.

Information on the duration of partnerships was limited, however, some workplans did indicate specific conditions focused on a size limit on the number of participants in the project and a capping on the funding contributions during the project. Again, KDT JU workplan (under the Research and Innovative Action proposal) is a good example of this and indicates that the maximum size of the project is 50 participants, and that EU contribution per project would be capped at €12 million, with the maximum contribution per partner in a project being limited to 40% of the total EU funding for the duration of the project.[25]

The notable EU fusion focused investments that are mentioned below are parts of larger government funds that are focused on investments in disruptive innovations and technologies. In the case of **SPRIN-D,** there are specifications concerning the duration of time taken to consider proposals. Currently, only about 4% of the submissions are being further pursued and the selection process takes an average of 12 weeks, however, depending on external factors, a decision may take longer in some exceptional cases.

In the case of EIT KIC Inno Energy related call for proposals, the evaluation criteria for making decisions to allocate resources to projects is defined for the EU research and innovation programme 2021-2027 (Horizon Europe), as the following:

1. **Excellence** (35%)
2. **Impact** (25%)
3. **Quality and efficiency of the implementation** (30%)
4. **KIC portfolio strategic fit** and compliance with the financial sustainability principles and knowledge triangle integration (5%)
5. **EU dimension** for multi-beneficiary projects (consortia with a pan-European character involving at least two independent entities from two different eligible countries) (5%)

Among partnerships targeting **fusion in the US**, the decisions to allocate resources follow an organised review process. This follows either the process of an initial review of a proposal by the first team, followed by a second review by another team that takes the final decision; or an initial review of a concept paper, which is then followed by a submission of proposal, after which an anonymous peer review takes place. Similarly, in terms of rules on duration, there seem to be no cost extensions beyond the period of the grant across the programmes. However, there are a few exceptions to this, depending on the type of partnership and its needs. A few examples are listed below.

In terms of decisions to allocate resources, across all the **ARPA-E programs**, a concept paper is required for an initial review, candidates are then either invited to or discouraged from submitting a full proposal. After this step, an anonymous peer review and internal scoring metrics are used, based on practical realization of the objectives. It was not possible to access the internal scoring metrics that are used. When it comes to the rules on duration, no-cost extensions were granted to the projects (this is specific to ALPHA, BETHE and GAMOW), all of which had a duration of 36 months.

25 See KDT Workplan 2023: https://www.kdt-ju.europa.eu/sites/default/files/2022-12/KDT_GB_2022.36_WP_2023_signed.pdf

For **SBIR/STTR**, in terms of decisions to allocate resources, proposals first undergo a review of the commercialization plan internally at the Department of Energy (DOE), before technical narratives are sent for an anonymous peer review. In terms of rules on duration, the phase I grants are nine months, the phase II grants are two years and can receive no-cost extensions for up to another year.

The decisions to allocate resources are based on a review process that is organized by the **INFUSE** Team, with input provided to the Fusion Energy Sciences (FES) Program for final selection. The RFA applications are then evaluated and competitively selected in accordance with the Office of Science Review Criteria. The reviewers are then asked to comment on the value of the work from the company perspective. In terms of rules on duration, DOE anticipates making single year awards with a value of between $50,000 – $250,000 and a duration of 12 months. However, DOE will entertain requests of up to $500,000 in total value and/or duration of 24 months for work deemed to be of critical value by the company.

For **Milestone-based Fusion Development Program**, the decisions to allocate resources are based on the same process as that of the ARPA-E programs. Regarding the rules on duration, the funding process lasts 18 months with the current budget envelope allowing for further funding over a total of 5 years.

Among **UK partnerships**, the decisions to allocate resources are based on applicants responding to a selection questionnaire (UKAEA STEP program), an application list of questions (Challenge Scheme mentioned below), or submitting a proposal for validation and internal discussion. Regarding the rules on duration, across selected programs, there seems to be an opportunity for successful applicants to continue to receive funds. The ones listed below are the schemes that fall under the UKAEA Fusion Industry Program schemes.

In the **Equity Scheme and Voucher Scheme**, the decisions to allocate resources are made internally and in consultation with other investment teams after the submission of the proposal. Regarding the rules on the duration for the equity scheme, the investments remain to be one-off investments. Meanwhile, for the voucher scheme, £50,000 is the maximum funding provided, which is for a limited duration. However, it is possible to re-apply for further vouchers, but the rules on their use have not been made public. In the **Challenge Scheme**, decisions to allocate resources under the SBRI, are based on filling out application questions with a percentage of weightage per question. For instance, the application questions may follow the format mentioned below:

- Proposed idea of technology 5%,
- Technical project summary 20%,
- Current state of the art and intellectual property 15%,
- Project plan and methodology 10%,
- Organisation and Team expertise 15%
- Cost and value for money 10%
- Commercial potential 15%
- Scalability 10%

Regarding rules on duration, phase I is 12 months, phase II is 20 months. There will also be a possibility of additional funding to the successful applicants of up to £1,000,000 to £2,000,000 inclusive of VAT, for scalability.

In the case of rules on duration, for many of the projects, there are no cost extensions granted to projects, albeit there are certain exceptions, such as the Milestone-based Fusion Development Program, the Voucher Scheme and Challenge Scheme (that falls within the UKAEA Fusion Industry Programme).

2.3.3 Assessment frameworks and metrics

KPI monitoring and reporting

Some PPPs present an internal monitoring system, providing a KPI-based framework to track progress within each partnership. The level of complexity and systemisation of a KPI monitoring system varies among the studied partnerships. The PPPs administered at EU level, including the institutionalised, co-programmed and co-funded, provide rather detailed KPIs. Common to all partnerships, there is a set of indicators, such as the Horizon Europe "key-impact pathways" defined in the Horizon Europe Regulation[26] and applicable to all the programmes linked to it. This process also responds to the need for interim and final evaluation as part of the Horizon Europe's related decision-making process. In addition, there are specific Joint Undertaking (JU) indicators specifically designed to monitor and support European R&I partnerships.

Generally, KPIs help assessing the overall composition of projects funded under a partnership, monitoring aspects like the ratio of lower and higher TRLs, SME participation, level of civil society participation, the geographical composition of the consortia, etc. Next to these, specific KPIs exist for the individual partnerships, reflecting their individual objectives and targets. For instance, within the Batt4EU[27] (Co-programmed Partnership) KPIs include a number of funded projects with novel chemistries at TRL 4+, several demonstrations of production lines, improvement of environmental impact and toxicity, recycling rate and so on.

With regards to US partnerships targeting fusion, KPIs vary between programmes, although the main progress measure observed across programmes is commercial success: which of the grants led to true commercial traction, customers and innovation. In addition, progress and success monitoring occurs on the basis of IP generated and number of scientific publications, as is the case for INFUSE[28]. Based on expert consultations, for the grants administered under ARPA-E, the main KPI has been follow-up funding, while technical progress has been tracked towards fusion triple product (nTtau). Generally, every programme follows its own reviewing and monitoring procedures (an example is the review of the Advanced Reactor Demonstration Programme by the Government Accountability Office[29]).

Finally, for UKAEA programs, there is less information available on the existence and frequency of KPIs and monitoring systems. For the Small Business Research Initiative (SBRI), it is reported to have a system in place to analyse business impact. The latter follows metrics related to impacts of the programme in terms of employment, turnover and ultimately economic benefit (e.g. in Gross Value Added [GVA]). In particular, the analysis builds on a business survey based on self-reported impacts on turnover as well as an econometric estimation of the employment rate amongst firms awarded SBRI. For both measures, the aim is to translate the findings into GVA[30]. Based on the consultation of experts, other UKAEA programs have developed an early-stage monitoring system of the impact of workforce development, technology maturation, and IP generated from the work.

Risk sharing between parties

In the European PPP environment, risk can be defined as the "unexpected variation in value". In this context, risk management involves identifying the risks, assessing their potential impacts (in value or cost terms), and identifying a strategy to best manage them; with PPPs, this refers to sharing between the contracting authority and the project company. Of course, as the project unfolds, new risks emerge

26 https://eur-lex.europa.eu/eli/reg/2021/695/oj
27 [insert]
28 Available at : https://infuse.ornl.gov/wp-content/uploads/2022/07/Cummulative_INFUSE_Review_2022a.pdf
29 Available at: https://www.gao.gov/assets/gao-22-105394.pdf
30 See: https://www.ukri.org/wp-content/uploads/2022/05/UKRI-130522-AnEvaluationoftheSBRIJanuary2022-WEB-FINAL.pdf

or change, which requires continuous monitoring throughout a project cycle. For EU partnerships, a streamlined process was laid out by the European Investment Bank[31] for the management of risk, as follows:

- The assessment of value for money and, therefore, the choice of whether or not to use a PPP delivery model;
- The preparation and terms of the PPP contract, including the development of the payment mechanism, early termination and variation provisions;
- The assessment of expected lifecycle costs and, hence, affordability and budgeting for the PPP project (including the costs of further forms of government support, such as guarantees);
- The assessment of the bankability of the PPP project and the capacity of the private sector to deliver the project;
- The statistical treatment of a PPP project in line with Eurostat guidelines.

In existing programmes, both in-and outside of the EU, risks and corresponding contributions are managed in different ways. While all countries exercise direct procurement, some PPPs share part of the risk and costs of RDI. The risk sharing through contributions were discussed for the various programmes in section 2.3.3, but generally require contributions from the private participants of up to 50%, the contributions increasing as risk decreases. A profile of risks and contributions in EU programmes for fusion, and the relation to TRL is presented in section 3.3.

2.4 Conclusions

This section summarizes the main findings across the PPP schemes, highlighting some of the key characteristics to be considered in the design for a proposed EU PPP to foster innovation in fusion energy in chapter 4.

- **Objectives:** the overarching objective of an EU scheme is typically focused on supporting the leadership and competitiveness of EU industry. Objectives should be part of an over-arching strategy for the technology being supported, and may include relevant milestones. They should also come from the initiative itself as far as possible, to establish a successful new way of working.
- **Management and responsibilities:** the main features of governance of a PPP are common across most PPPs (governing body, executive body, general assembly/membership, advisory board). The main differences relate to the level of public involvement in governance. For fusion, if the goal is for the industry to take greater ownership and responsibility in DEMO, this should be reflected with industry involvement in governance, e.g. with at least a 50:50 balance between the public and industry representatives.
- **Intellectual property:** rules for this vary by partnership with the main distinctions being on whether the private participants receive ownership of the outputs and under what terms. Most often conditions are attached, such as requiring that some outputs are jointly owned, that some are available for public access (particularly scientific relevant outputs), or that the private firm commits to work in the jurisdiction where the PPP operated.
- **Funding:** within the EU, funding arrangements typically require significant matching funds to be provided by the counterparts to the EU, these can total 50% or more (45% in the case of EUROfusion). In the US and the UK, it is more common, particularly for smaller amounts, start-ups and/or low-maturity technologies, that these are provided more on a grant-type basis, with no matching funds required. However, in the US, in the latest PPP programme (the Milestone-based program) matching funds are now also required. There is the option for matching funds to be accounted through in-kind contributions.
- **Decision and award processes:** are typically based on a staged-review process. Following a call for proposals – with terms drawn up by the management (with the involvement of the advisory board),

[31] EIB, EPEC PPP Guide. Available at: https://www.eib.org/en/readonline-publications/epec-ppp-guide-welcome

a concept paper, a proposal or a questionnaire is requested. This outlines what the project aims to achieve, the challenges it will tackle and how it will do it. This is most often reviewed by expert technical advisors, specific teams or anonymous peer reviews. A further detailed proposal stage may also be requested. Specific milestones should be set and agreed upon as part of these processes, these can relate both to timing and technical achievements.

- **KPI monitoring and reporting:** these typically split into a few types, including: those focused on the internal processes, e.g. amount awarded, number of awards; those focused on outputs, e.g. jobs created, impact on GVA, patents registered; those focused on technical, scientific or other achievements e.g. triple product values. Naturally, indicators are also linked to the objectives of the scheme, e.g. to achieve progress on raising TRL in a particular area.
- **Risk sharing:** the EIB sets out a useful process for assessing how risks can best be shared in a PPP arrangement, these include a focus on the contractual and payment provisions, costs and budgeting, the bankability of the outputs, and the capacity of the private sector to deliver. The latter elements are particularly relevant for fusion. Overall, it is always necessary for industry/research partners to make own contributions in a partnership (rather than procurement) arrangement, typically in-kind (time and resources), and with these contributions ranging from 5-50% of the total cost.

3 NEEDS AND LANDSCAPE FOR A FUSION PPP

This chapter presents a mapping of the needs of the main stakeholder groups from a PPP in fusion energy. This is followed up with an analysis of the policy landscape for a PPP for fusion in the EU.

3.1 Needs of Fusion community from a PPP

In this section, we provide a mapping and analysis of the stakeholder input collected throughout this study, as part of the interview process, as well as during the common workshop . The interview questions focused on the role and interest of the stakeholders within the European and international fusion supply-chain, as well as their views on the relevance and characteristics of a fusion PPP. Furthermore, the stakeholder workshop focused on discussing a preliminary assessment of various PPP schemes and first considerations to elaborate a fusion scheme with the goal of assessing the willingness and rationale of the European private sector to engage in fusion development.

To build an overview of European private stakeholders, the specific purpose of mapping was to gather information on:

- Ongoing activities and developments in the fusion sector;
- Technological components, challenges and solutions in the area of fusion;
- Technologies developed in other sectors that can be used in fusion;
- Private and public entities engaged in fusion activities along with their relationships and the organisational, financial and contractual characteristics of their cooperation;
- Identifying European private stakeholders with an existing or potential role in accelerating the development of fusion energy.

In order to identify and discuss the specific needs of each stakeholder group, and their implications for an EU PPP for fusion, the mapping is then complemented by the information collected during the stakeholder consultation process. In what follows, the needs of the fusion community are reported per stakeholder group. The following stakeholder groups are considered:

- Fusion industry (supply chain);
- Fusion start-ups;
- Investors;
- Research labs;
- Government.

3.1.1 Needs of fusion industry (supply chain)

The fusion industry supply chain has primarily been developed through involvement in ITER and other publicly funded devices such as W7-X and the JT-60SA. Other publicly funded devices either being built or in the pipeline in Europe include DTT in Italy and IFMIF-DONES in Spain, and the largest project on the horizon, DEMO, the pilot fusion power plant to follow-on from ITER. Each project provides opportunities for industry. Especially DEMO, as it moves from concept to more detailed engineering design and eventually construction, will provide significant opportunities, eventually attracting billions of euros for the European fusion industry. However, many of the private fusion initiatives globally are also already- or about to-start building their proof-of-concept devices in the next 5 years. The opportunities in the supply chain for the private industry are conservatively estimated at around EUR 500 million per year[32] and are expected to grow much further in the coming years. This highlights an important need for the sector as a whole –

[32] FIA (2023) The Fusion industry supply chain: Opportunities and challenges

to grow and achieve greater scale. In the following section we first present a short profile of the different segments of the fusion industry supply chain, followed by a summary of needs.

Note: In the following sections we provide a handful of examples of firms in different segments of the supply chain. These examples are not exhaustive, only illustrative, many more EU firms are active in the fusion supply chain.

EU Manufacturing firms

Within the EU fusion supply chain, there are a wide range of private sector stakeholders that contribute to producing and supplying components that are integral to the functioning of a fusion power plant. This can include supplying superconducting magnets, cryogenic lines and other components necessary for the vacuum vessel, divertor systems, laser diodes (for inertial fusion), laser assembly, etc. One such example is ASG Superconductors, which is responsible for supplying superconducting magnets and are amongst the few companies supplying these components to ITER. Another example is Elytt Energy which is also responsible for designing, manufacturing and distributing superconducting magnets for particle accelerators, including ITER.

An example of a larger industrial company includes French multinational company Air Liquide, which is responsible for supplying to ITER cryogenic lines, which play a key role in circulating cold liquid helium from the cryogenic production plant to the reactor and then return heated helium to the factory. Similarly, Italian company, SIMIC, which is known for manufacturing vacuum vessels and cryostats, is a major supplier for the ITER project, supplying components linked to the magnetic system, divertor and vacuum vessel. In terms of examples of companies that focus on an ICF approach, glass company Schott is a key supplier of laser amplifier glass and the raw material fused silica. Another such company includes German industrial machine manufacturing company Trumpf, which is responsible for laser assembly and manufacturing laser diodes which have potential applications in fusion and have been discussed with both Marvel Fusion and Focused Energy, the two EU ICF start-ups.

EU Engineering firms

Similar to manufacturing needs in the EU fusion supply chain, engineering services are indispensable to the design and operation of a fusion power plant. It is essential to engage engineering from the design phase, to deal with the integration, planning and the entire project management. Stakeholders within this category are required to provide a range of services, from managing the assembly of the fusion reactor components to supporting the engineering and construction of cooling water systems, test blanket systems, central cooling systems and checking the qualifications of a range of other essential equipment.

Examples of stakeholders in this category include Assystem, a dedicated partner in the development of low carbon technologies, that has been providing engineering services to the ITER project. They are responsible for managing the assembly of the ITER reactor components and are also working on the completion of a Divertor Remote Handling System to ensure maintenance of the reactor. Spanish entity Empresario Agrupados has been involved in the design phase of ITER. They are presently developing the engineering and construction of the 36 ITER buildings, the Tokamak Cooling Water System, the Test Blanket Systems, as well as the design and manufacturing of the central cooling system. International engineering services company, Tractebel Engineering, is supporting the qualification process, by monitoring and supporting the qualification activities performed by ITER. The qualification of equipment is critical to ensure that the equipment is working smoothly under all conditions from seismic loads to radiation, static magnetic fields and so on.

EU Construction sector

Stakeholders within the EU construction sector are playing an important role in meeting all the infrastructure requirements of fusion power plants, given that the om a reactor (e.g. ITER) to a power plant (e.g. DEMO) will require large scale construction considering the inclusion of all needed components with adequate space arrangements. This involves infrastructure required to set up the buildings that house the reactor and the diagnostics and management systems amongst other essential facilities. French construction and concessions company Vinci is working to provide a wide range of infrastructure for ITER. This covers infrastructure for the creation of the buildings that will house the Tokamak reactor, the diagnostic and management systems and a tritium facility. Similarly, Spanish entity Empresario Agrupados is responsible for the construction of the ITER buildings. Another example is French company Spie, that has a four-year maintenance contract for the ITER buildings and infrastructure[33].

EU Nuclear companies

The creation of a complete fusion power plant (e.g. from ITER to DEMO) requires bringing together the expertise of large industries which are experienced in the operation of large-scale power plants given the similarities in some areas and the nuclear expertise (much less than fission but still relevant). This stakeholder category consists of large industries that have interest and experience to build on in the design phase of a fusion plant and can help to avoid operational hurdles and technological difficulties. In addition, for some of these players, project management and engineering capacities of the nuclear industry might also be of interest to deal with the entire life cycle of a plant (from construction to dismantling). Companies like Daher, Framatome, Equipos Nucleares, or Tecnatom may be important actors to share their view on the way the construction phase can integrate all specificities, from operation to maintenance. This is given the fact that the management of the fuel and the physical and thermochemical constraints the equipment will face during operation, is important to consider during the design phase. These firms may also have a role in the integration of the various individual components and systems into a fusion power plant (FPP) which meets nuclear safety and regulatory requirements.

EU Energy Sector

The EU energy sector is a key stakeholder that will play a crucial role in the future. Energy sector stakeholders are the ones that are expected to invest in powerplants, operate them and sell the resulting product generated from fusion energy, i.e. electricity. This includes utilities and other energy companies, such as those in oil and gas that are looking to diversify their portfolio. Since fusion is expected to become commercial in the long term, we currently see only a limited number of EU energy sector companies actively working or investing in it. One such example is Italian energy group ENI which has invested in US-based Commonwealth Fusion Systems and the Divertor Test Tokamak (DTT) in Italy to accelerate the industrialisation of fusion energy[34]. Despite the involvement of the energy sector being more relevant in the long-term, it can be important to include them in the discussion on a PPP approach, since it would be beneficial for them to get a first understanding of how the fusions sector might evolve.

Others

In addition, there are numerous other industrial and services sectors active in the fusion supply chain. These include, for example, **logistics** firms responsible for the transport of very large, heavy components; **raw materials suppliers**, indirectly for main materials, and more directly in some areas such as refined lithium.

[33] See: https://www.euro-energie.com/le-consortium-dalkia-veolia-et-f4e-collaborent-sur-le-projet-iter-n-5262

[34] See: https://www.eni.com/en-IT/media/press-release/2023/03/eni-signs-new-collaboration-agreement-with-cfs-development-fusion-energy.html

Summary of needs

The FIA report on the fusion supply chain provides some important insights into the **needs of suppliers**, including:

- A strong perception of **the size of the potential opportunity** in fusion.
- A **high confidence** from existing suppliers that they **can produce at scale and that this will be required in future** – however, at the same time suppliers perceive investments as risky at the current stage as it is unclear when fusion will commercialise and if the fusion approach they supply will be successful.
- For **clearer direction** from the fusion industry and government about **long-term component needs** and production scales.
- A **need for financing mechanisms** to help minimise and share risk – including public support for R&D and scaling, and long-term financial commitments from private industry and public funders.
- **Long-term contracts** and **commitments** from customers.

Other feedback from firms also highlights the importance of continuity in commercial opportunities for companies active in the supply chain, and that public funding should help to create a pipeline of projects for firms so that staff and know-how developed by supplying to ITER are not lost in the coming years. This was highlighted as an important short-to-medium term risk as parts of the work to supply ITER are completed.

In addition, consultations with stakeholders during the work also highlighted a number of key needs, as follows:

In terms of the **main objectives** for an EU PPP programme for fusion, the companies considered that a major focus should be placed upon addressing the challenges associated with Key Enabling Technologies (e.g., tritium breeding, first wall materials, remote handling etc), enhancing cooperation between the relevant stakeholders, and bringing in private sector expertise to accelerate the progress from fusion reactor to an energy power plant, since the public sector is moving at a slow pace. In the context of DEMO as a possible objective, during the focus group sessions some industry stakeholders signalled a need to share their views during the design and conceptual phase to enable most efficient work towards the goals.

A few common opinions that were raised by several stakeholders were focused on risk sharing, source of financing, IP and technology transfer and duration of processes. Stakeholders stressed the need for **risk mitigation measures**, since the companies cannot bear extremely high risks, such as unlimited liabilities. In terms of risk sharing, across the interviewees, there is a strong preference for a high level of risk to be borne by the public sector, especially in the case of a demonstration project, where the focus is on developing and demonstrating a fusion concept. The stakeholders mentioned that they could envisage a 50% risk sharing option if there is a high potential to commercialize the product for other sectors (within a specific range of time), hence resulting in a lower level of risk for the private sector. Some also indicated that a **difference** should be made **between system suppliers** (tier 1) **and component suppliers** (tier 2), since component suppliers were likely to have a lower level of risk tolerance, as they are typically smaller and more bound to specific technologies for which the rationale to invest is weaker.

Another suggested distinction was put forward regarding fusion companies (start-ups) and non-fusion companies, the latter bearing a higher risk in these partnerships given that fusion is not their core business, and therefore having more at stake when investing into a fusion PPP. On the other hand, a type of **risk specific to small-medium manufacturing enterprises** is what can be called staff saturation: e.g. if an enterprise of 100 employees has 50-60 of them dedicated to a large fusion project for several years, exposing the organisation to the risk of not developing other areas or customers whilst the success of their involvement in the PPP is uncertain. It was highlighted that investment of resources into a PPP should always be reflected in an active involvement in the project, especially for smaller actors.

Regarding **source of financing**, most of the stakeholders indicated that there was a strong preference for grant-based funding from the public side, along with the expectation that a majority of the funding should come from the public sector. This point of view was also echoed by participants across focus group sessions, many of whom reiterated the point that **whilst they would be able to contribute to a PPP, to varying extents** depending on the specifics, **the public sector should not expect major investments from industry at this stage**. Representatives of engineering firms indicated a cost-sharing model should be considered, along with a consideration of in-kind contributions from industry. Stakeholders representing SMEs indicated that they would need at least 90% funding to develop a project, however, in this case the source of financing could be a mix of public sector money, along with a large-scale private entity. A few mentioned the possibility of equity-based financing. Moreover, stakeholders agreed on the preference for a milestone-based award programme. Some respondents have highlighted that prior to identifying the financing source and mechanism, there needs to be a steering entity within the partnership which provides leadership to the whole process, which can come either from private or public side.

In terms of **IP ownership and management**, the majority of the stakeholders believe that they (industry) should be able to retain the IP. However, there are also views that if the public sector is financing the project, there should be some level of sharing considered. Most stakeholders have agreed to maintain the current system in place for ITER commissions, separating background and foreground IP, the former remaining with the participant, while the foreground being shared within the partnership. However, a representative from a smaller manufacturing firm called for specific flexibilities: granting access to specific background knowledge if necessary for the realisation of the component/system that is part of the foreground. In addition, when considering the development of an IP of a certain system or eventually the powerplant, there would be a public/national interest in wider dissemination of this knowledge to more quickly scale up fusion power. In this case, a requirement for a licensing regime may be an option. Important to note that participants also mentioned (during focus group sessions) that when it comes to DEMO, it would be useful to co-design together with labs, however rules regarding the IP would need to be dealt with.

Finally, regarding the **duration of processes**, most of the stakeholders mentioned that the duration of contracting processes can be very long. This is reflected in **bureaucracy** that is often seen as too heavy. The need to address bureaucracy linked to the duration of processes was stressed upon multiple times by participants during focus group sessions, i.e. that a PPP must enable less bureaucracy and quicker decisions. Several organisations have made the claim that current contracts with F4E have necessarily to be slimmed down from the management perspective. Some made recommendations to consider and include experience that is available in the international research community regarding establishing contracts between partners, specifically on hi-tech components, since this involves a negotiated procedure.

3.1.2 Needs of fusion start-ups

This category contains the EU start-ups that focus on delivering a fusion reactor. The two main technology routes are represented in the EU start-up sector, e.g. Magnetic Confinement Fusion (MCF), and Inertial Confinement Fusion (ICF), but as of now, no Magneto-Inertial or other approaches.

Many of the players that fall within this category, are startups that have emerged in recent years, such as Renaissance Fusion that raised $15 million in a 2022 seed round. Renaissance Fusion are working on building a stellarator fusion reactor, using high-temperature superconducting magnets and liquid metal shields. Another startup, Marvel Fusion, which focuses on the usage of short-pulse laser and nanotechnologies to trigger non-thermal nuclear fusion reactions. While these startups have a lot of collaborations with different public sector institutes for the purpose of research and knowledge transfer, they both have mostly raised funds from the private sector. Other players, such as Novatron Fusion, whose approach is a novel variation on MCF, has raised around EUR 3 million in a seed round through a PPP, which includes grant money from EIT Inno-Energy and KTH Royal Institute of Technology, where EIT have taken an equity share in Novatron.

The start-ups have a variety of needs, both for themselves to progress their ideas towards proof-of-concept devices, with the supply chain to be able to build their devices, and also to engage with knowledge sharing and exchange with public research institutions.

A recent FIA report on the fusion supply chain[35] provides some important insights into the **needs of fusion start-ups**, highlights include:

- Some start-ups note a **lack of innovation at suppliers**, where despite being highly technically skilled and having supplied public fusion programmes, they are not used to the demands and speed demanded by the private sector.
- Companies use a mix of off-the-shelf materials and **components and specialist fusion industry suppliers**, most companies (81%) having some need of the latter.
- The supply chain will **need to build capacity**, become more agile, improve their products and processes and reduce costs to effectively serve the industry in future. Particularly there is a need for the supply chain to reduce lead times to help iterate much more rapidly. Acknowledging that there is a balancing act for suppliers in terms of risk and investment to deliver these improvements, scale and innovation.
- Existing **supply constraints** are evident, especially for power electronics, magnets and high-temperature superconducting (HTS) wire. However, firms were relatively confident that medium-term needs could be satisfied by the supply chain.
- A need for **funding – both public and private** to show there is consistent demand for fusion which will increase the confidence to invest. This can include public funding towards enabling technologies.
- A need for a **strong supporting framework** – encompassing long-term commitments, strategy, regulation, investment in the workforce, promotion of fusion and a stream of tangible projects for the supply chain to be involved in.

In terms of **main objectives** for an EU PPP programme for fusion, the start-ups, similar to the supply chain, considered that a major focus should be placed upon urgently addressing the challenges associated with Key Enabling Technologies (e.g., tritium breeding, first wall materials, remote handling etc), enhancing cooperation between the relevant stakeholders to ensure a free-flowing exchange of ideas and working on the concept, design and demonstration of prototypes. Startup representatives also indicated that there are some technologies (e.g., breeding blankets and other technologies which are likely to have only fusion as a market opportunity) in which the private sector has made limited progress, and where there remains a need for public institutions to lead.

A few common and diverging opinions that came up amongst several startup representatives was the **potential lack of 'serious money'** i.e., large amounts from established investors, needed to finance fusion, views on IP ownership and management, lack of urgency from the public sector and (too) lengthy award processes. Some start-up representatives also mentioned that they lacked some capacity and expertise to handle PPP projects.

In terms of concerns regarding **sources of financing**, certain start-up representatives drew direct comparisons with the ability of entrepreneurs, investors or tech companies in the US being able to invest large sums of money, and sometimes having a level of wealth that the risk of failure does not have large financial consequences for them, so that they are willing and able to take larger risks than those in Europe. In comparison, in Europe, there is limited availability of similar capital for fusion related

[35] FIA (2023) The Fusion industry supply chain: Opportunities and challenges

investments. In this context, during the focus group sessions, certain participants were sceptical about EIT Inno-Energy (who have funded and taken an equity share in Novatron Fusion) being able to play a significant role, particularly due to the small size of funding and that it is not exclusively dedicated for fusion. The lack of funding and programmes in the EU risks that EU-founded companies focus their efforts elsewhere. For example, in August 2023, Marvel Fusion a German ICF fusion start-up, announced that its next facility, a $150 million public-private venture will be built in the US with Colorado State University[36]. Their chief operating officer noting "*The US is much further ahead in this respect, there are clear milestone-based funding programmes, as well as a regulatory framework with a clear planning horizon.*" They also noted that the German fusion energy strategy was not supported (at the time) by concrete budgets, and that there is no instrument at the European level either. "*That has to change, and something must be developed here so that we can tackle our next project in Europe and Germany*". Recent announcements in Germany at least should help to mitigate this in future but were too late to avoid this investment being 'lost' to the US.

Most of the startups indicated that there should be upfront grant-based funding, however a few indicated that a cost-sharing agreement could be interesting. Moreover, in terms of **award processes**, all the startups interviewed indicated a **preference for milestone-based programmes**, where some indicated that an increasing amount and type of funds should be disbursed as the TRL goes up.

Regarding **IP ownership and management**, there was a diverse range of views. Some start-up representatives believed that not everything linked to the IP needed to be protected, enabling it to be 'mostly open' to the public. Others believed that the core IP of startups is part of their business model and therefore should not be shared. However, if it was the case that the IP needed to be shared due to the involvement of public money, they indicated that there should be an option for the startup to acquire the IP afterwards (possibly in partnership with the industry) and later commercialize it. Still others indicated that while the IP might in certain cases be owned by academia (keeping in mind the technology transfer from labs to industry), the industry would need to lead the PPP and be responsible for managing the IP. Additionally, recommendations were made to consider having an advisory board on IP management. Finally, on the duration of processes, the start-ups indicated that working with the public sector led to **long, tedious processes** and hence recommended that concrete timelines be put in place to set up contracting processes that do not take up to a year to establish.

3.1.3 Needs of investors

Investing in fusion energy innovation has become an attractive option for a range of EU investors, from angel investors to venture capital firms, sovereign wealth funds and so on. Examples of these stakeholders include SET Ventures in the Netherlands that invested in General Fusion and Earlybird Venture Capital, a venture capital firm focused on making investments in European technology innovations that invested in Marvel Fusion, leading a Series A round that raised €35 million[37]. One of the key reasons to include investors in the discussion on a PPP approach is because it is important to understand how investors see the risk sharing and IP ownership elements as they often have board representation, and these characteristics of a PPP can materially affect their investment.

The potential for significant long term returns on investment and the opportunity to contribute to the development of sustainable energy solutions, make investing in fusion energy an attractive option. Investors are typically open to invest in all types of fusion approaches, bringing a portfolio approach to their investments. They rely on external experts (such as consultants, universities, research labs) to varying extents to provide the due diligence and technical and scientific advice to make their decisions.

36 https://www.cleanenergywire.org/news/german-start-marvel-fusion-invests-us-laments-lack-support-europe

37 See: https://marvelfusion.com/series-A/

Exit strategies vary for investors, and the potentially long timelines to secure a return on their investment requires patience. Average lifetimes of venture funds in general are around 14 years, some shorter (5-10 years), some longer (up to 20 years), which provides some scope for an investment in fusion to come to fruition but stretches beyond the EU timeline for a first fusion power plant (FPP). However, it is not unlikely that commercialisation will take longer than this time horizon. Opportunities to cash-in investments may arise prior to commercialisation for example where one investor class sells to another, e.g., venture capital to an institutional investor as the technology nears market and value increases.

To date, investors have primarily focused on investing in fusion start-ups, and have not played a significant role in investing in companies in the fusion supply chain. However, there may be opportunities for investments of this type. One example of this is Kyoto Fusioneering, a Japanese fusion company founded in 2019. Kyoto Fusioneering does not intend to build a fusion plant on its own, but rather to develop and innovate key components (with a focus on tritium fuel cycle, power cycle and gyrotrons) to sell to others in the sector. They have attracted around EUR 90 million in funding from investors[38]. This provides one, limited, example of how the supply chain industry may also be able to attract private investors.

In general, in the fusion energy sector, investors need for the public sector to:

- Play a facilitating and enabling role;
- Continue funding basic research and supporting early-stage development;
- Create a clear and risk-proportionate (favourable) regulatory framework;
- Invest in the development of the fusion supply chain;
- Provide a supportive and stable policy framework – including demonstrating a commitment to fusion technology, providing necessary financial incentives, and fostering PPPs;

The last point on PPPs is the most important for this work. Investors of all types can be interested in public-private partnership programmes, the reasons including the opportunities to:

- **Leverage their investment** - by partnering with governments and other organisations investors can access additional financial resources, which may also support in accessing other government funding and grants.
- **Work alongside established entities in the clean energy sector** – to access expertise and research & development facilities that can help accelerate the development of fusion energy technology
- **Reduce investment risk and increase potential returns** – by drawing on the credibility and independent verification typically brought to a PPP by the public sector involvement.

Additionally, by **partnering with governments** and other organizations, some investors (e.g. venture capital firms, corporate investors) can help to shape the direction of the clean energy sector and help **drive policy changes** that can benefit the industry as a whole, such as reform of regulatory and market frameworks. For many investors, particularly Sovereign wealth funds, PPPs can be a way to align their investments with the strategic priorities of their respective countries. More detail on specific investor types is provided in Annex D.

As part of the **stakeholder consultation**, an investor pointed out that their investment in a fusion start-up was an exception for them and with their investment model they would look for an exit at some point (as the average lifetime for venture capital is around 14 years). They mentioned that it helped that the UK government and Canadian **government also provided funding to the start-up**, thereby showing support. According to them, **IP remains a significant issue**, but given the societal value of this technology they suggested that governments could buy out shareholders of IP and make it

38 https://kyotofusioneering.com/en/news/2023/05/17/1478

public, providing some reward to the investors and preventing big players from simply acquiring fusion companies.

3.1.4 Needs of research labs

The needs of this group of stakeholders in the EU are heavily centred on the EUROfusion roadmap (which is currently being revised) and therefore their efforts and attention are on scientific progress to support ITER and now, increasingly towards DEMO. Going forward, the focus on DEMO is expected to increase. The research labs and organisations are wrestling with a number of questions relevant for involvement in a PPP, particularly including:

- Ownership and sharing of knowledge and IP – is a concern as these organisations often hold significant relevant knowledge which private firms, especially start-ups, wish to access, but the value of sharing this is unclear to the labs. The labs find that if the private industry has little to reciprocate, then exchange is not attractive, nor are they usually permitted under budgetary rules to 'give something for nothing'. Clear rules and agreements on background and foreground IP would help to establish trust, as would the private firms being more willing to share their scientifically relevant outputs;
- Scientific publication – it is still one of the key metrics and necessities for publicly funded research. A PPP arrangement would also need to contribute to the scientific outputs of the research organisations.
- Role of labs – it needs to be clearly and fairly defined as often they are asked to check and interpret data to verify outputs. This carries a risk to the organisations, particularly if they are involved in setting and/or evaluating milestones in a PPP.
- Legal issues – a PPP can be attractive to be involved with, however there can be legal issues around liability and procurement rules. The nature of the organisation is particularly an issue for EUROfusion which is not a legal entity. Resolving these issues would support effective engagement in a PPP.
- Bureaucracy – the labs find that they are tied to public bureaucracy which slows down their decisions and restricts their scope for action. A PPP can be attractive to address the need to move faster.
- Research – labs are clear that they see a continuing need for publicly funded research for fusion, in multiple areas where there are scientific gaps and that this is consistent with the long-term goals of fusion energy. They also see the need for and advantages (compared to ITER) of increased involvement of industry in DEMO design and future steps.
- Two-stream approach – not all labs have the capability, interest or resources to participate in a PPP arrangement. This may need a two-level approach for those that can and those that can't participate in this way.
- Talent management – labs also highlighted that Europe has a high number of talented scientists and staff, and that greater partnership with industry was needed to develop career pathways for their staff, e.g. to avoid losing them to other sectors or countries when PhDs finish. This would also provide benefits in knowledge transfer.

3.1.5 Needs of government

The needs for this group of stakeholders are relatively straightforward they need to move towards achieving their policy goals, typically set out in a strategy or roadmap – with the end goal being fusion energy which meets societal needs for a clean, zero-emission, secure, affordable energy source. Important secondary needs include (1) securing economic growth from investments in fusion energy, e.g. by supporting the competitiveness of companies active in the sector and the jobs and economic activity associated with their success; (2) cost-efficiency and accountability. As government must account that money has been spent usefully, this may lead to cumbersome processes and risk-averse decision making.

A PPP approach enables the government to take a more hands-off role in managing public spending, reducing the bureaucratic burden and can free up the designated organisations to take more risks. Yet the arrangement also allows for the government to set some or all conditions and objectives for a PPP which satisfy the need to meet societal goals. It can also help to take more urgent action, which is particularly relevant to a sector such as fusion where alongside scientific collaboration there is also a global competition and race towards the first fusion power plant. Some programmes such as ARPA-E in the US and SPRIND in Germany deliberately use PPP mechanisms to take risks that normally neither the public or private sector alone would take. Some experts[39] also argue that the government should ensure a return on investment for the state, to help fund further innovation activities, this could be for example through taking a 'golden share' in intellectual property or outputs of the partnership.

3.2 Summary of needs from a PPP for fusion

Based on the stakeholder needs presented in the previous sections, the following principles will be important for the selected PPP mechanism or approach to accommodate:

Need for a PPP

- **Clear need for a new funding mechanism for industry involvement in fusion, and a PPP approach provides the best way to do this.** From industry in particular, but also from start-ups and the research community, there was clear view that additional funding mechanisms were needed to accelerate progress in the sector and build the fusion ecosystem in the EU. This was also noted as important to avoid the gap between ITER and DEMO leading to a loss of know-how and competences from the EU industry. Additionally, that a PPP mechanism offered the best way to transfer the world leading expertise from EU research institutions to industry and this could be focused on addressing the key challenges for fusion power.

Objectives

- The **overarching objective should be an EU fusion power plant**. A clear signal on this objective for the EU as part of a fusion strategy is needed, to support the sector as a whole. There is a strong consensus from the public fusion community that the fusion power plant of this objective is DEMO as they see it as the natural successor to ITER based on the current understanding of the scientific and engineering challenges. Meanwhile, start-ups believe DEMO is unsuitable for numerous reasons, not least the long timescales and the scale of funding, they hope that they themselves would more quickly produce a pilot plant of their own and therefore that the objective should be open. The private industry (supply chain) is more ambivalent as their products and services would be needed in either case.
- In terms of main objectives for an EU PPP programme for fusion, there is a common consensus that **addressing the challenges associated with Key Enabling Technologies** (e.g., tritium breeding, first wall materials, remote handling etc) **should be a key priority**.
- **Enhancing cooperation between different stakeholders across the sector is also seen as crucial** not only to share risk and support technology transfer, but also to increase interaction and cooperation – to build a whole ecosystem. This should acknowledge the importance and value of the knowledge held by the research community but also the need for this to be transferred to industry as fusion moves towards a pilot plant.
- It should be **a goal of the PPP is to accelerate progress towards fusion**, borrowing the urgency of the private sector and reducing the bureaucracy and caution of the current public driven processes e.g. those used for ITER procurement.
- The PPP should **catalyse the sector towards commercialisation where industry and other capital begins to invest in innovation in fusion independently**. Public funding through the PPP should aim to support the long-term creation of a commercial market for fusion.

[39] Mazzucato, M. (2015) The Entrepreneurial State

- **Clarification is needed on how the EU wants to fund and engage with European fusion start-ups** – EU start-ups requested greater clarity.

Governance, roles and responsibilities

- **A PPP by its nature requires a leading role for industry in governance,** this will move away from the procurement-supplier relationship that has characterised industry involvement to date e.g. through ITER, Broader Approach.
- **The PPP should support participants to leverage their strengths, best practices and procedures**, defining their roles and responsibilities accordingly.
- **Reducing bureaucracy, retaining accountability**, a clear desire for faster decision making and lighter processes was expressed, but it was also acknowledged that some elements of bureaucracy are hard to avoid since public sector funds need to be held accountable.
- **The roles of F4E and EUROfusion should be clarified.** The latter could benefit from becoming a specific legal entity which would allow it to take on more roles and responsibilities in a PPP. F4E can bring significant technical and administrative capacity, industrial networks and funding and also has a clear mandate in the fusion space, using this in the best way will be important to the success of an EU fusion strategy and PPP.

Funding and contributions

- **Expected contributions from industry will need to be consistent with the industry view on the immaturity of the sector**. It is not realistic at this stage of development that the industry invests significant resources directly itself as there is currently no business case for fusion as a whole and timelines are uncertain, even though there is a general belief that eventually fusion will succeed. Whilst industry should be expected to contribute in a PPP, the main contribution would need to be public. This balance should evolve over time as TRL levels increase, or for specific components if there are more immediate opportunities for commercialisation.

Intellectual property

- **Knowledge transfer as a key goal of the PPP will require mutually acceptable agreements on intellectual property**, established processes for dealing with background and foreground IP offer standard principles to deal with this issue, but it is feasible that negotiations on treatment of IP would be specific to each interaction/activity. Licensing or preferential access arrangements could also be valuable tools to balance the needs of participants.
- **Industry needs to be able to take ownership of at least some of the IP produced through a PPP to see the value in its participation and contributions**. This is typically a pre-requisite from their investors and to make the internal business case for participation in a PPP.
- **The labs and universities and broader public sector need to be fairly compensated for their contributions and also to have access to scientific and research-relevant outputs of the PPP**. The research partners also have an interest in becoming joint owners of IP developed jointly under a PPP.

Activities, calls and award processes

- **Milestone-based activities were preferred by almost all stakeholders**, noting that it is important to frame a PPP with concrete milestones in the short term, supported by proven technology, in order to attract some level of funding from private companies. It is also important to ensure that the milestones have sufficient technical and or scientific challenge and are aligned with the objectives of the PPP.

- **Funding application process:** For any PPP, the funding application process should not take too long, this was an important critique of existing programmes. Administrative burden should be avoided, as it increases risks and direct costs.

Related challenges

- **Lack of readily available talent in the fusion workforce:** There is a constant need for workforce talent since industry (fusion and other sectors) often lures away skilled professionals in the sector. There is a need for training programmes in fusion to ensure a pipeline of skilled staff comes into the work-force. In order to retain the top staff, and maintain their interest and knowledge in fusion, they need a continued pipeline of fusion projects to work on. A PPP could address training or on funding the project pipeline, or both. These points were underlined in the focus group sessions and stakeholder interviews which indicated a high need for manpower and specialised expertise in fusion, including undergraduate and master's degrees, as well as PhD programmes. Additionally, the opportunity to include radiation studies and courses for lawyers to understand the regulatory framework needs were also mentioned.
- **Regulatory aspects to support fusion:** Regulatory aspects need to support fusion interests, just as is the case in the UK and the US. Again, it has been emphasised that the use of nuclear fission regulation is a serious barrier to fusion and would be disproportionate, adding significant costs to the sector. EU Member States need to move faster on this front since they are lagging behind in the global competition with the US and the UK already deciding on accommodating regulations that support fusion. It may be smart as part of a PPP to include an consultation activity at EU level on fusion regulation, inviting industry and national regulators to discuss approaches and consistency across MS.

3.3 Policy landscape

3.3.1 EU-level landscape

A public-private partnership for fusion in the EU needs not only to fit within the existing policy framework, but also to address existing gaps. This section provides an overview of the most relevant aspects in the current policy landscape covering legal frameworks, key stakeholders, funding frameworks and existing programmes that could be interesting for fusion and a fusion PPP. The purpose is to clearly identify the gaps that exist to inform the development of a PPP.

Euratom

Euratom plays a crucial role in governing and supporting the development of the fusion industry within the European Union. Established in 1957 by the Euratom Treaty, it operates as a distinct and parallel legal structure to the EU, with its own specific mandate focused on nuclear research and development. While both Euratom and the EU share some common institutions, Euratom's primary objective is to coordinate and promote research on nuclear energy, including the advancement of fusion technologies. Administered by the European Commission (EC), Euratom collaborates with member states, research institutions, and industry stakeholders to foster innovation and knowledge exchange in the field of fusion energy.

As a part of its efforts to drive fusion research forward, Euratom is closely linked to programmes like Horizon Europe. Within the Horizon framework, the **Euratom Research and Training Programme**[40] plays a pivotal role in funding and supporting research initiatives in fusion energy, with EUR 583 million allocated to fusion research and development for the period 2021-2025, of this EUR 549 million is

[40] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/euratom-research-and-training-programme_en

allocated to EUROfusion. Through this funding Euratom is able to finance various fusion projects, support research collaborations, and facilitate the development of innovative technologies in pursuit of sustainable and clean nuclear energy solutions. Any fusion PPP would have to comply with the legal framework of Euratom.

Fusion in Euratom research programmes

Horizon Europe sets the primary framework for funding research and innovation in Europe. This is also relevant for fusion research and development where Euratom aligns with Horizon Europe and two key strands are funded:

(1)ITER: the majority of Euratom research and innovation resources are centred on the development, construction and assembly, and eventual operation, of ITER as well as the development of a new generation of scientists and engineers trained in this field. Euratom is used to fund **Fusion for Energy (F4E)**, a Joint Undertaking and the EU Domestic Agency which manages the EU contributions to ITER. In the 2021-2027 period EUR 5.6 billion is allocated for this purpose.

(2)Research: The other branch of EU fusion funding via Euratom is distributed through **EUROfusion** to fund research at EU labs and research centres. The research aligns with the EUROfusion roadmap which captures a broad ITER-DEMO focused pathway to fusion, including a focus on the preparatory concept and design work for DEMO and on key enabling technologies, but treats these primarily from a scientific rather than engineering perspective.

F4E and EUROfusion

F4E and EUROfusion are two of the leading organisations for fusion in the EU and important in the context of any European initiative on fusion. The former being responsible for EU contributions to ITER, the latter for EU fusion research.

F4E, was established as a Euratom joint undertaking, and has three overarching objectives[41]:

1. To **provide the contribution of Euratom to ITER**, in accordance with the Agreement on the Establishment of the ITER International Fusion Energy Organisation for the Joint Implementation of the ITER Project (the ITER Agreement);
2. To **provide the contribution of Euratom to Broader Approach activities** with Japan for the rapid realisation of fusion energy (Broader Approach Activities), in accordance with the bilateral Agreement for the Joint Implementation of Broader Approach Activities (the Broader Approach Agreement with Japan);
3. To prepare and **coordinate a programme of activities** in preparation for the construction of a **demonstration fusion reactor** and related facilities including the International Fusion Materials Irradiation Facility (IFMIF).

The latter objective can include a number of different activities that could contribute to the preparation and construction of a demonstration fusion reactor. In addition to its overall objectives, F4E has also adopted an industrial policy, the key objectives of which are:

1. **Deliver the European contributions to ITER and the Broader Approach** within the agreed budget and schedule making best use of the industrial and research potential and capabilities of all F4E members, in line with the competition rules
2. **Broaden the European industrial base for fusion technology for the long-term development of fusion** as a future energy source and **to ensure a strong and competitive European industrial participation in the future fusion market**;

[41] From 2007/198/Euratom

3. **Foster European innovation and competitiveness in key emerging technologies** to progress the development of the *Innovation Union* and its impact at the international level.

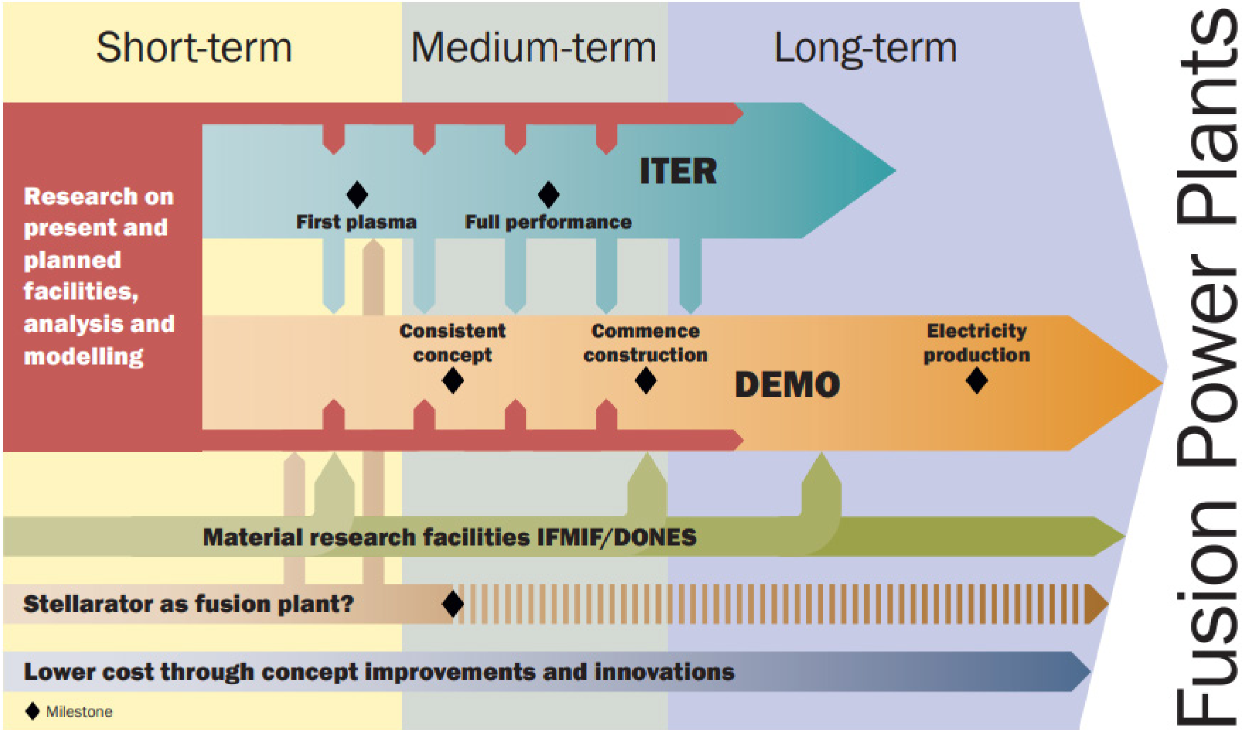
The focus to date has been on Objective 1, and this has spurred the first wave of industrial innovation, but now as EU contributions to ITER construction and manufacturing are increasingly completed, then the focus of F4E can move to address the other objectives. This can potentially spark a new round of industrial innovation to keep the interest of the industry and reduce the risk that know-how and capabilities developed for ITER are lost. The objectives 2. and 3. strongly align with the objectives of this work provide the basis for F4E involvement in a potential EU PPP for fusion. We understand that F4E is currently developing a technology development programme (TDP) as part of their new Industrial Policy which will set out priorities for their future work with industry and towards DEMO. The governing board (consisting of MS representatives) has given two mandates for the redesign of F4E's strategy, to reflect recent changes in the fusion development context:

1. Target strategy to develop and sustain the mid-and longer-term fusion technology industrial capacity in the EU; and
2. Establish a Working Group to define strategic procurements.

EUROfusion is a co-funded European Partnership which is a consortium of 31 research organisations. In addition to the budget from the EU (via Euratom) of EUR 549 million for 2021-2025, a further EUR 450 million (over the 2021-2025 period) is provided by MS. Whilst EUROfusion coordinates and distributes the funding it has no legal form, therefore there are limitations to what it can authorise or be party to.

EUROfusion coordinates the EU fusion research community in line with the "European Roadmap to the Realisation of Fusion Energy", its two main roles are (1) to prepare for ITER experiments through a fusion science programme; and, (2) to develop a concept for the future demonstration fusion power plant (DEMO), the latter a responsibility partially delegated from F4E. An overview of the Roadmap is provided below, which shows the main thrust through ITER and then DEMO to a fusion power plant in the long term, with supporting actions on materials research (IFMIF-DONES), investigation of stellarators as a potential alternative to tokamaks and other concept improvements and innovations. Within the roadmap more specific detail is provided on eight missions to be addressed to realise fusion (plasma regimes, heat-exhaust systems, neutron tolerant materials, tritium self-sufficiency, safety, integrated DEMO design, competitive cost of electricity and stellarators). In the short to medium term of the roadmap (the timeframe of a potential PPP) the focus is on securing ITER success and laying the foundations for DEMO. The roadmap includes some attention to the role of industry and identifies many of the same needs and drivers for industrial involvement relevant for a potential PPP, including the need for industry involvement in DEMO design (particularly engineering linked tasks in the early phases), technology transfer and retaining know-how and competences developed through ITER. An addendum to the Roadmap (not yet public) has been prepared in summer 2023 and is undergoing discussion with key stakeholders before adoption.

Figure 3-1 EUROfusion roadmap overview



Horizon Europe Partnerships

Horizon Europe is the primary instrument for funding research and innovation in Europe. It funds European Partnerships which account for a large share of the overall budget. Four types of European Partnerships are possible:

1. **Co-programmed European Partnerships** – are typically between the EC and private (but sometimes public) partners. Objectives, commitments and governance arrangements are set out in Memoranda of Understanding between the parties. 11 candidate co-programmed European Partnerships were approved, and will receive more than €8 billion between 2021 and 2030. Feedback from stakeholders and our own assessment suggests that this is the most appropriate of these potential partnership approaches for fusion. These are explored further below.
2. **Institutionalised European Partnership (under Article 185 or 187 of the Treaty of the European Union [TFUE]) –** between the EU, Member States and/or industry. These partnerships require a legislative proposal from the Commission based on either a decision by the European Parliament (Article 185) or council regulation (Art. 187). These are intended to only be used when other types of partnership would not achieve the desired objectives or impacts, and are implemented by dedicated structures. They require also a matching or greater (e.g. 50-75%) financial contribution from the partners. We assess that fusion is not at a level of maturity for the matching investments from private partners, nor does it yet have the high level political support to adopt such a partnership.
3. **Institutionalised Partnership / EIT KIC –** European Institute of Innovation and Technology (EIC) Knowledge and Innovation Communities (KIC) are also institutionalised partnerships and support: reinforcing the journey from research to the market, innovation projects, business incubators and accelerators, as well as training and education programmes. The primary partners are private companies (investors, industry, innovators), research organisations, educational institutions, and other stakeholders. Nine KICs are established, fostering cross-disciplinary innovation partnerships, entrepreneurship, and knowledge exchange within specific topic areas (such as climate change,

sustainable energy, digital technologies, health, raw materials, and more). The Inno-Energy KIC focuses on sustainable energy and in 2022 has invested in a first EU-based fusion start-up, Novatron Fusion[42] (see also section 3.2). The broad scope of the KIC can be relevant for an EU fusion PPP and there is demonstrated investment in fusion, but it is unclear if such a mechanism is more broadly suitable for the intended purposes of an EU fusion PPP given the apparent focus on start-ups and relatively small investments.

4. **Co-funded** – partnerships involve primarily public stakeholders from member states, research institutions and public authorities. Due to the public focus these are not suited for a PPP targeting private fusion industry innovation.

For the 2021-2024 period 49 candidate partnerships were identified (see Figure 3-2 where a summary of 38 of the partnerships is presented), with 11 of these identified under cluster 5: Climate, energy & mobility, which would be the pillar under which a fusion PPP should sit[43]. A second Strategic Plan of Horizon Europe 2024-2027 will need to be prepared, which provides an opportunity for the proposed PPP mechanism to be developed in this work.

As part of this plan a set of draft concept papers for 10 candidate European Partnerships for 2025-2027 were published in July 2023, these cover six co-funded and four co-programmed:

- **Co-funded:** Brain health; Forests and Forestry for a sustainable future; In-orbit demonstration and validation; Raw materials for the green and digital transition; Resilient cultural heritage[44]; Social transformations and resilience.
- **Co-Programmed:** Innovative materials for EU (I'm for EU); Solar photovoltaics; Textiles of the future; Virtual Worlds.

If a European Partnership is the desired model for a fusion PPP then such a concept draft should also be developed for the consultation period, which ends in September 2023. However, different time frames are conceivable in the Euratom Research and Training Programme as it has a five-year-duration extended by two years through a new Council Regulation to match the Horizon Europe seven year lifecycles.

[42] https://www.innoenergy.com/discover-innovative-solutions/online-marketplace-for-energy-innovations/novatron-reactors-for-stable-fusion-plasma/

[43] It should be noted that the Euratom Research and Training Programme under which EUROfusion is funded is intended to complement the Horizon Europe programme.

[44] Preferred co-funded, would also consider co-programmed

Figure 3-2 Horizon Europe – European Partnership candidates 2021-2024

OVERVIEW OF 49 CANDIDATE EUROPEAN PARTNERSHIPS

PILLAR II - Global challenges & European industrial competitiveness

CLUSTER 1: Health	CLUSTER 4: Digital, Industry & Space	CLUSTER 5: Climate, Energy & Mobility	CLUSTER 6: Food, Bioeconomy, Agriculture,...
Innovative Health Initiative	Key Digital Technologies	Clean Hydrogen	Circular Bio-based Europe
Global Health Partnership	Smart Networks & Services	Clean Aviation	Rescuing Biodiversity to Safeguard Life on Earth
Transforming Health Care Systems	High Performance Computing	Single European Sky ATM Research 3	Climate Neutral, Sustainable and Productive Blue Economy
Risk Assessment of Chemicals	European Metrology (Art. 185 of the TFEU)	Europe's Rail	Water4All "Water security for the planet"
ERA for Health	Artificial Intelligence, Data and Robotics	Cooperative, Connected and Automated Mobility (CCAM)	Animal Health and Welfare*
Rare Diseases*	Photonics	Batteries "Towards a competitive European industrial battery value chain"	Agroecology "Accelerating Farming Systems Transition"*
One Health / Antimicrobial Resistance*	Made in Europe	Zero-emission Waterborne Transport	Agriculture of Data*
Personalised Medicine*	Clean Steel - Low Carbon Steelmaking	Zero-emission Road Transport (2ZERO)	Safe and Sustainable Food Systems*
Pandemic Preparedness* *Co-funded or co-programmed*	Processes4Planet	People-centric Sustainable Built Environment (Built4People)	
	Globally Competitive Space Systems**	Clean Energy Transition	
		Driving Urban Transitions to a Sustainable Future	

Institutionalised Partnerships (Art 185 or 187 of the TFEU)
Co-Programmed
Co-Funded

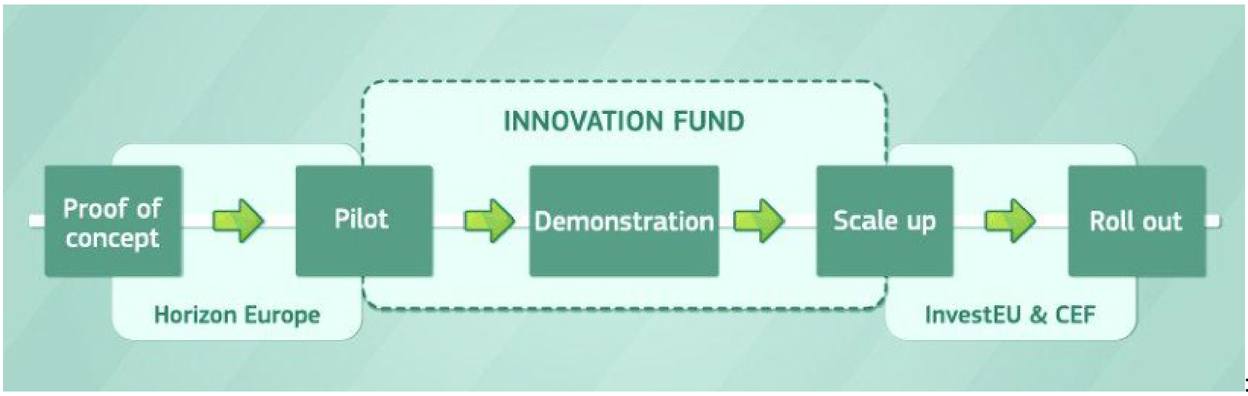
* Calls with opening dates in 2023-24
** Calls with opening dates not before 2022

Euratom-specific partnership

Euratom can set up joint undertakings within and outside the Horizon Europe framework described above in the context of institutionalised partnerships. Unlike the EU joint undertakings, the Euratom joint undertakings can also be commercial companies incorporated under the laws of any EU member state and could be a relevant option in advanced stages of the development of fusion energy such as the construction stage of DEMO or fusion power plants. Although in the field of fusion the Euratom joint undertakings have taken the form of public partnerships (JET Joint Undertaking, F4E), there have been several other models in the past for the construction of prototype fission reactors.

Other EU research and innovation instruments of relevance

There are other funding instruments in addition to Horizon Europe. Other instruments could potentially play a role in funding fusion innovation. The following figure highlights a few of the instruments that may apply, showing that beyond Horizon Europe, the innovation fund and InvestEU can address the next levels of technical maturity:



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- The **Innovation Fund** is the EU's flagship fund for demonstration and commercialization of innovative low-carbon technologies (renewable energy, electrolysers, heat pumps, hydrogen and energy storage), funded by EU-ETS proceeds and focusing on the development of solutions for industry and supporting its transition to climate neutrality. The Fund typically funds projects for up to 60% grant funding or 100% in the case of competitive bidding. It focuses on the mid to later stages of the TRL scale, and projects are expected to be sufficiently mature in terms of planning, business model, and financial and legal structure. In the latest (3rd) round of awards selected projects were evaluated by independent experts against five award criteria: ability to reduce greenhouse gas emissions compared to traditional technologies; level of innovation; operational, financial and technical maturity; scalability; and cost effectiveness. In the short-term, the 3rd large scale call will be launched in Autumn 2023, but most of the new topics were created to support REPowerEU objectives and a quick gas phase-out, therefore the weighted maturity requirements[45] of a fusion project would not meet this short-term objective. In the medium-term, it also seems unlikely that fusion energy would score sufficiently high against the five award criteria, particularly operational, financial and technical maturity, but also potentially scalability and GHG emissions reductions as although these are both possible, they are quite distant, and the key enabling technologies for fusion that might also be supported would not deliver emissions reductions on their own. Also, as it stands, the Innovation Fund has not released calls where nuclear technologies would be eligible, it is unclear if it would be possible to include fusion in a future call. For these reasons, the Innovation Fund is not a strong potential source of funding for fusion innovation in the next 10 years or more. We would expect that only from around the mid-2030's fusion may have developed enough to receive funding from this instrument, and it could be a suitable vehicle as an EU fusion public-private partnership for pilot plants.
- **InvestEU** is one of the leading EU programmes intended to spur growth and investment in the EU between 2021-2027. It intends to trigger more than €372 billion in investment in this period through

[45] https://climate.ec.europa.eu/eu-action/funding-climate-action/innovation-fund/large-scale-calls_en

the InvestEU budget guarantee of €26.2 billion. Implemented by the **European Investment Bank (EIB)** and its agencies such as the **European Investment Fund (EIF).** One of its latest programmes is the **Strategic Technologies for Europe Platform (STEP)** which includes a branch on clean technologies, however this does not include fusion on the list of considered technologies. The EIF has an SME focus and has a technology transfer product that could support European fusion start-ups. It also invests more broadly but typically via investments in other funds. The EIB offers a variety of funding instruments, such as Venture Debt[46], that could be of interest to the fusion sector, but are not representative of a PPP approach. Overall, InvestEU and associated funds have a focus on more mature technologies or start-ups, the latter may be of interest to fusion, and SMEs in the fusion supply chain may be able to access equity or debt finance through EIF supported funds. However, InvestEU is not a suitable instrument for an EU fusion PPP at this stage.

- **Breakthrough Energy Catalyst EU**[47] is a partnership between the EU and private investors. It aims to mobilize up to €820 million between 2023 and 2027 to support emerging climate technology projects. It targets projects with high potential for impact and cost reduction in specific sectors, including clean hydrogen, long duration energy storage, sustainable aviation fuels, and direct air capture (of CO_2). Prioritizing projects that are ready-to-build within 9-12 months, the programme aims to fund two types of projects: demonstration projects (TRL 5-7; project size between ~€30M-100M, venture debt and grant funding) to de-risk earlier-stage technologies, and Large First-of-a-Kind (FOAK) Projects (TRL 6+; project size between ~€100M-1B, equity and grant funding) focused on technology scale-up and market creation. At this stage, neither the fusion energy supply chain nor start-ups would be eligible for such funding. Such a fund may become interesting for start-ups that wish to build future demonstration plants, but this prospect is likely more than 10-20 years or more in the future. It is not therefore a suitable vehicle for fusion energy at this point in time.
- **Net Zero Industry Act** although not an instrument in itself, the recent decision to include nuclear technologies, including fusion, within the Act's innovative net-zero technologies to support[48], means that the range of applicable funding schemes could increase. It also helps create a policy landscape consistent with the introduction of a fusion PPP scheme.

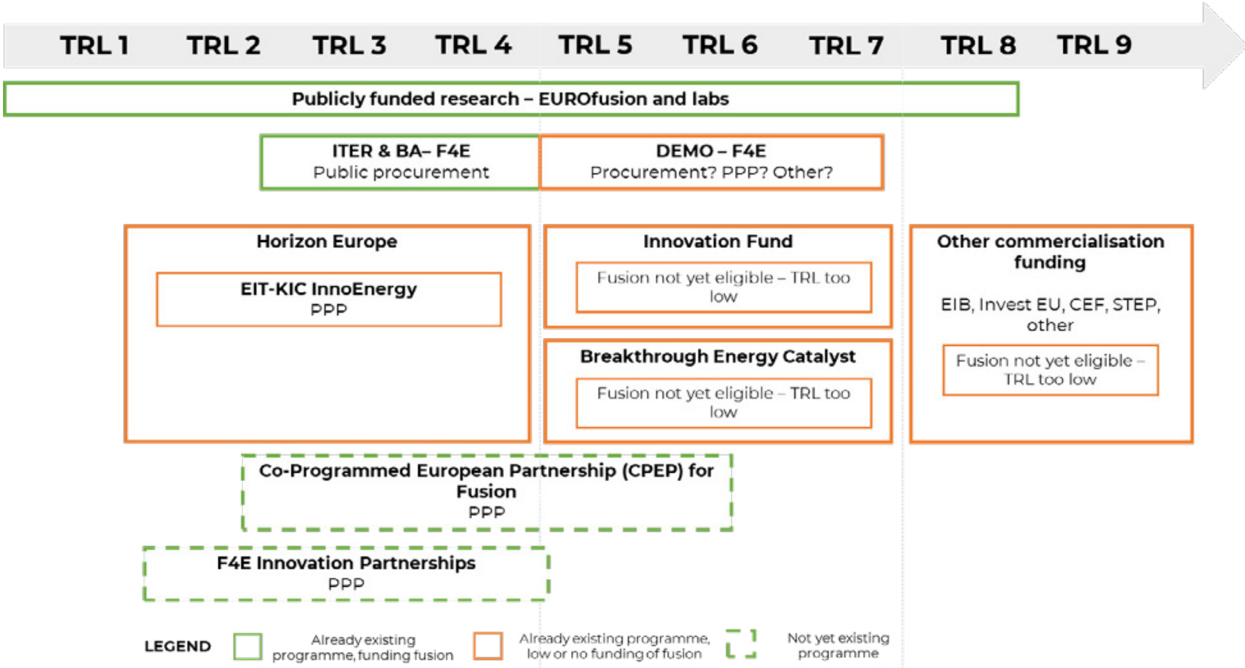
Summary of EU funding for fusion

The current EU funding landscape for fusion energy is summarized in Figure 3-3, where the main gaps are highlighted, i.e. outside of ITER and related activities (e.g. Broader Approach, IFMIF-DONES) and EUROfusion there is little additional funding at EU level for fusion. There is a potential gap in public support for industrial fusion innovation as funding for ITER declines as it nears completion, a large scale-up of funding for DEMO remains likely 10 years or more in future, and there are limited routes to support EU fusion start-ups (where so far only a single investment has been made, in Novatron Fusion, by the EIT-KIC InnoEnergy).

There are possibilities under Horizon Europe for further funding, for example expanding or earmarking part of the EIT-KIC InnoEnergy budget for fusion, or creating a Co-Programmed European Partnership (CPEP), these are amongst the main measures later considered (see section 4.2) for stimulating private industry involvement and innovation. Given the low maturity (TRL) of fusion as a whole and many of the main key enabling technologies, neither the Innovation Fund, the Breakthrough Energy Catalyst nor other commercial funding is yet applicable to fusion, although these may become relevant in future and could for example play a role in the construction of a demonstration fusion plant and eventual pilot fusion power plant. In the below figure we marked already existing programmes for fusion with green; programmes that are not yet funding fusion with orange, and potential/non-existing programmes with blue.

46 https://www.eib.org/en/products/equity/venture-debt/index.htm
47 https://breakthroughenergy.org/our-work/catalyst/eu-catalyst-partnership/
48 https://www.euractiv.com/section/energy-environment/news/eu-lawmakers-reintroduce-nuclear-in-green-industry-tech-list/

Figure 3-3 Overview of EU funding landscape for industrial innovation in fusion



3.3.2 National programmes of relevance for fusion in EU Member States

National funds for fusion research and development can play an important role in advancing fusion as a viable energy source, complementing the programmes led or coordinated at EU-level through Euratom. Alongside their involvement in EU initiatives, some Member States also pursue some work on fusion independent of the other programmes. These national programmes allow countries to tailor their research priorities and strategies, addressing specific challenges or exploring novel fusion concepts, which can eventually supplement an EU-wide fusion programme. Some of these initiatives also adopt a PPP approach, a few leading examples are profiled below:

Germany

The German government has committed to investing more than one billion euros in fusion research over the next five years. Research Minister Bettina Stark-Watzinger announced a new support program valued at 370 million euros on top of the already assigned funding. This financial support is intended to bolster ongoing activities at institutions such as the Max Planck Institute for Plasma Physics, the Karlsruhe Institute of Technology (KIT), and the Research Centre Jülich until 2028. The aim of these investments is to create a collaborative "fusion ecosystem with industry" to accelerate the development of a fusion power plant in Germany[49].

In a published white paper[50] by the Federal Ministry for Research, the government sets two overarching objectives in its fusion strategy: the diversification of investment to further develop technological approaches, and the creation of a national fusion ecosystem. This is aimed at knowledge and technology transfer across industrial and lab actors in Germany, building on the existing rich international network. In the white paper the need for an adequate legal (regulatory) framework is also mentioned, particularly outside of nuclear law.

49 https://www.cleanenergywire.org/news/german-research-ministry-plans-boost-nuclear-fusion-development

50 https://www.bmbf.de/SharedDocs/Publikationen/de/bmbf/7/775804_Positionspapier_Fusionsforschung.pdf?__blob=publicationFile&v=2

One of the main current activities for funding radical innovation fusion in Germany, and an example of a PPP arrangement, is **the SPRIND programme,** modelled after DARPA (and ARPA-E) in the US, and specifically aims to develop deep tech innovations. It has announced the creation and funding of a company, **Pulsed Light Technologies Gmbh,** which aims to bring laser-driven fusion technologies closer to the market within the next 5-7 years. The company will provide funding exclusively for fusion-related applications of laser technology, this aims primarily to support the development of two Germany-based ICF fusion start-ups, Marvel Fusion and Focused Energy. The approach also enables versatility in utilizing laser systems for various purposes beyond fusion, i.e. with an eye on broader commercialisation opportunities. The PPP will operate by establishing cooperation agreements with the start-ups, who will contribute part of their intellectual property and staff, part of which can be contracted by the PPP. The company will then focus on developing the laser systems and procuring relevant R&D services from the industry and research labs to support this, with this procurement following public tendering processes to ensure transparency as the funding comes from the government. The aim of this PPP model is to leverage the strengths of both public funding and private companies to accelerate the development and deployment of laser-driven fusion technologies.

CEA (FR)

The French CEA (*Commissariat à l'énergie atomique et aux énergies alternatives*) publicly funded nuclear research organisation has launched a substantial grant program called "*Reacteur Nucleaire Innovant*" financed by the "France 2030" investment plan, which devotes EUR 1 billion to the nuclear sector (fission and fusion) and could include step-wise funding of initiatives, with for example three funding steps of EUR 10 million, EUR 80 million, and EUR 200 million, with later steps unlocked as agreed milestones are met. This type of scheme can be attractive to fusion start-ups and also potentially the supply chain.

DTT (IT)

The Italian national advanced energy agency, ENEA is leading a consortium composed of Italian research institutions, the energy company ENI, government and regional partners and international stakeholders to conceive the Divertor Tokamak Test (DTT) project. The consortium was established in 2019 and has raised nearly EUR 500 million to construct the facility[51]. The facility is based in Frascati (Rome) and aims to conduct scaled experiments to explore and test the physics and technology of divertor concepts for the exhaust of the plasma thermal power which could be used in a fusion power plant, testing different technologies for the building of such device. The DTT facility will examine different magnetic configurations and incorporate components utilizing liquid metals and other suitable solutions to address the issue of thermal loads on the divertor. The DTT facility's crucial objective is to advance these solutions, both from a physics and technology perspective, and achieve a sufficient level of maturity and integration. The consortium approach to a major project, incorporating a variety of public and private stakeholders offers an example of a PPP approach that could be more widely emulated.

3.3.3 International landscape

United States

Over the past 20 years, fusion research has been supported in the United States through the National Nuclear Security Administration (NNSA), the Office of Fusion Energy Sciences (OFES), the US Advanced Research Projects Agency-Energy (ARPA-E) and a smattering of funding from the National Aeronautics and Space Administration (NASA). The current Administration has added momentum to fusion energy through the announcement in the past year of the **Bold Decadal Vision**, with the aim of accelerating fusion energy in the US.

[51] https://www.enea.it/it/seguici/pubblicazioni/pdf-volumi/2019/dtt_idr.pdf

The Fusion Energy Sciences (FES) program within the Department of Energy's Office of Science, which funds most of the government's fusion research, will receive a funding $763 million for 2023-2024[52]. Funds in the FES program are earmarked for: $130 million for research at General Atomics' DIII-D, $104 million for NSTX-U operations at Princeton Plasma Physics Lab, and $242 million for ITER. Inertial Confinement Fusion (ICF) research, which supported the breakthrough at the NIF, comes from a separate budget allocation, through the National Nuclear Security Administration (NNSA). Congress announced to fund $630 million for Inertial Confinement Fusion of which at least $380 million will go to funding the NIF[53]. This will total a record **$1.4 billion funding for fusion by the US government**, in line with the announcement in March 2022 of a "Bold Decadal Vision" for commercializing fusion energy that would accelerate beyond the plans outlined in the fusion community's plan[54].

An important part of the funding is directed towards the various programs and PPPs active in the US, most notably the ARPA-E programmes, the Milestone-based Programme and the Innovation Network for Fusion Energy (INFUSE). The various US funding programs and PPPs present diverse objectives and technological focus. For instance, ARPA-E programmes specifically target those high-risk, potentially high impact options at low TRL that have the potential to become **cost effective/low-cost** solutions.

Based on a review of awarded funds, we can summarise the following:

- **ARPA-E ALPHA** funded projects (9 projects, $32.7m) focusing on Magneto-Inertial Fusion (~80% of funding), i.e. novel alternative approaches, and to a lesser extent MCF and IFE. The program awards reveal a strong focus on plasma regimes of operations (almost totality of funds involved projects with this focus), together with heating systems and magnets. The start-ups Zap Energy and Helion Energy both emerged from this program.
- **ARPA-E BETHE** (18 projects $43.7 m) has a more distributed focus across the different fusion approaches. Around half of the projects were focused on research on a fusion approach, and around half had a specific Key Enabling Technologies (KET) focus, with magnets (HTS), heating systems, diagnostics, software, and modelling and simulation amongst the focus. The start-ups Commonwealth Fusion Systems, Type-One Energy and Zap Energy were among those leading funded projects, however most were led by national labs and universities. Realta Fusion and Princeton Stellarators are start-ups that resulted directly or indirectly from this program.
- **ARPA-E GAMOW** (14 projects, $26.5m) awarded funds targeting projects from all technological approaches to fusion, while focusing almost exclusively on Key Enabling Technologies, particularly for neutron tolerant materials and tritium self-sufficiency.
- **Milestone Program** funding, a total of $46 million went to a set of technological approaches including tokamaks, ICF, stellarators and others. The awards, of up to 50% cost-sharing, have been made to consortia led by fusion start-ups, who have partnered with research labs and other companies.
- **INFUSE**, comprising partnership awards of up to USD 250k (effectively a voucher scheme for industry to access lab expertise) requiring 20% cost-sharing, aims to accelerate basic research to develop innovative fusion energy technologies in the private sector. In 2023, around 30 awards have been made, investing in diverse projects across the different fusion approaches and KETs. Over the last years many more INFUSE projects have been awarded.

An important regulatory development was the announcement by the Nuclear Regulatory Commission (NRC) in April 2023, that fusion energy will be regulated under the NRC's byproduct materials framework. This approach will provide fusion developers with the regulatory certainty necessary to drive innovation and investment growth. In particular, this approach separates the regulatory framework for fusion from

52 https://www.fusionindustryassociation.org/congress-provides-record-funding-for-fusion-energy/#:~:text=Congress%20would%20fund%20%24630%20million,amount%20from%20the%20U.S.%20government.

53 Ibid.

54 Ibid.

the utilization facility framework applicable to nuclear fission energy and will allow the US to tailor its regulatory approach to the emerging fusion energy sector. This is considered a crucial barrier to be overcome in the regulation of fusion, in the same way as it is being addressed in the EU and other jurisdictions around the world. The option advanced by the NRC would focus on regulating the potential radioactive materials in fusion plants (i.e. tritium) and align fusion systems with similar technologies, such as a particle accelerators.

UK

In the UK, the Fusion Strategy[55] sets out ambitious goals for fusion energy research and development in the UK. Presented in 2021, it has two main goals, namely demonstrating commercial viability of fusion and bringing this technology to commercialization. The strategy aims to achieve these through the UK Atomic Energy Authority (UKAEA), which is the UK's primary research institution responsible for advancing fusion energy technology. The strategy aims to establish UK's dominance in three key areas: international leadership, scientific advancement, and commercial ventures. Although the UK Fusion Strategy encompasses all technological methods related to fusion energy, the research initiatives outlined primarily center around MCF and have a focus on Spherical Tokamaks through the **STEP programme** which aims to build a demonstration Spherical Tokamak by around 2040. A site for STEP has already been selected and the Fusion Industry Programme is engaging industry in the early design and conceptual work.

As part of its strategy on fusion, UKAEA has developed specific instruments and facilities to address specific objectives and challenges, including:

- **Mega-Amp Spherical Tokamak-Upgrade (MAST-UPGRADE)**: a UK national fusion experiment used to demonstrate an exhaust system capable of managing the intense heat of the plasma;
- **Remote Applications in Challenging Environments (RACE):** a division providing robotic solutions that enable maintenance in challenging environments to take place with remote techniques;
- **Materials research Facility (MRF):** Facility developing and examining materials that can withstand the conditions inside a fusion plant;
- **Hydrogen-3 Advanced Technology (H3AT):** tritium research centre studying how to process, store and recycle tritium;
- **Fusion Technology facilities (FTF):** facility testing components in realistic fusion conditions, developing innovative engineering techniques.

In September 2023, the UK government unveiled plans to establish new research and development initiatives to support the fusion sector in the UK and enhance global cooperation, in line with the UK Fusion Strategy. This decision comes in the wake of choosing not to participate in the Euratom Research and Training program[56] and consequently, the F4E support for ITER.

To implement this comprehensive package, the government intends to allocate funding of up to £650 million until 2027. This funding is in addition to the £126 million allocated in November 2022 to bolster R&D efforts in the UK's fusion field.

The PPP programmes administered by UKAEA as part of the **Fusion Industry Programme** are structured around three schemes, targeting different barriers to fusion R&D funding:

- **Challenge scheme**: engaging and supporting UK businesses to overcome important technical challenges in fusion, developing valuable intellectual assets and capabilities within the UK private sector supply chain;

55 https://www.gov.uk/government/publications/towards-fusion-energy-the-uk-fusion-strategy
56 https://www.gov.uk/government/news/government-announces-up-to-650-million-for-uk-alternatives-to-euratom-rt

- **Voucher scheme**: making it easy for UK businesses to access facilities offering specialisms in fusion technology giving them access to bespoke expertise and technologies;
- **Education scheme**: increasing the supply of highly skilled workers and researchers into the fusion sector.

The new alternative fusion R&D package will encompass the following elements:

- Establishment of new facilities, specifically designed to expand fusion fuel cycle capabilities and foster innovation;
- Implementation of a fusion skills initiative, ensuring the development of the necessary expertise and capabilities required to realize our fusion strategy;
- Further support for enhancing collaborative international projects;
- Implementation of additional measures to expedite the commercialization of fusion technology, including bolstering the STEP program;
- The UK intends to extend the collaboration with the EU and other international partners, while developing its own autonomous strategy for fusion.

Japan

In April 2023 Japan unveiled a national plan aimed at advancing the industrialization of fusion energy. This plan underscores the significance of bringing together both public and private sector initiatives to facilitate the commercialisation of fusion energy. The strategy, which was formulated by the Cabinet Office, emphasizes fusion energy's role in enhancing energy security, mitigating the effects of the climate crisis, and affording early pioneers and adopters a competitive edge on the global stage. Furthermore, the report stresses the urgency of expediting and synergizing collaborative efforts between the public and private sectors to achieve the goal of commercialization.

The primary objectives of this strategy are to nurture the fusion industry, propel the advancement of fusion technologies, and encourage innovative approaches. Japan's strategy[57] also encompasses various specific initiatives, including:

- Establishing a Fusion Industry Council to facilitate collaboration among industry, academia, and government sectors;
- Expanding support for research and development by private companies and startups;
- Engaging in regulatory discussions with international partners;
- Conducting research on fusion technology and exploring means of supporting research efforts;
- Accelerating the Fusion DEMO program;
- Creating additional avenues within the government for the development of fusion;
- Enhancing fusion-related activities within university settings.

3.3.4 Summary of gaps

Based on the overview of EU-wide, national and international policy landscape, we identify the following policy gaps :

- **Public funding for the EU fusion industry is tailing off as ITER progresses, and a long gap is likely before DEMO brings similar funding opportunities.** The EU fusion sector is following the EUROfusion roadmap which is focused on the success of ITER and then DEMO. However, from the industry perspective, there is a gap emerging in publicly funded manufacturing and supply chain work for fusion as many EU components for ITER are completed and DEMO is unlikely to begin construction

[57] https://www8.cao.go.jp/cstp/fusion/230426_strategy.pdf

until well into the 2030's at the earliest. Other projects such as IFMIF-DONES and DTT, amongst others, offer some opportunities for the industry in the short-medium term, as does the growth of the private fusion sector, however, this could well be insufficient in many areas. This risks the loss of capability and know-how from the EU industry.

- **There are almost no other EU funding instruments for fusion outside of F4E and EUROfusion, leaving industry with little support.** EU funding for fusion is channelled almost exclusively to ITER (and the Broader Approach, IFMIF-DONES) by F4E and by EUROfusion to research and scientific development. Whilst the former has used industry heavily, it is now scaling back, and the latter is almost entirely focused on the labs, universities and research centres, not industry. There is almost no other EU funding for the fusion industry.
- **There is scope for F4E to invest more in industrial innovation, geared towards a demonstration fusion power plant, but currently nearly no non-ITER or Broader Approach activities.** Similarly EUROfusion sees a need for greater industrial involvement in DEMO but only small steps are being taken.
- **There are potential funding options for fusion through Horizon Europe, including for public-private partnerships.** Horizon Europe partnerships can provide a mechanism for funding fusion, one that provides a PPP-based model, and variations of which have already been used via Euratom to fund fusion work, i.e. the Co-Funded approach for EUROfusion. For industry, a Co-programmed European Partnership appears to be the most promising and suitable option from the range of existing options available.
- **Other EU funding mechanisms are primarily geared towards innovations that are closer to market** which make them broadly unsuitable for fusion funding in the short-medium term. For a very few specific components or technologies with high maturity levels and broader commercial potential there may be limited potential for funding through these mechanisms.
- **There is very little EU support to date for fusion start-ups, with the exception of one investment/grant provided via EIT Inno-energy to Novatron Fusion**. Potentially further funds could be accessed in this way, or also via EIB-EIF funding. However, this lack of funding is a risk, reflected in the investment by Marvel Fusion in the US, not Europe, for its next facility.
- **EU funding is almost entirely MCF**-based. The ICF approach has achieved noteworthy milestones at NIF in the US in the last year, and the EU industry is a world leader in industrial laser technologies for high-intensity applications. There remains a gap in EU funding for ICF which doesn't capitalise on this EU industrial expertise and EU-based start-ups, and could represent a missed opportunity.
- **National programmes can potentially fund some areas not covered at EU level.** The examples in Germany on lasers for inertial fusion start-ups, in France on a potential milestone-style programme for nuclear (including fusion) and the DTT model in Italy; all demonstrate where national funds are either filling gaps (DE & FR) or complementing EU funds (IT).
- **Urgency and speed.** Stakeholders were clear on the urgency of the need for a funding programme, noting the urgency communicated by the US Bold Decadal Vision and the speed at which Milestone-based Program for Fusion was created and then made its first awards. This program was announced in Sept 2022[58] and first awards were already made, following a selection process, in May 2023[59], a period of only 9 months. This speed in award processes and urgency in strategy was a gap observed by stakeholders.
- **The recent increase in fusion funding internationally reveals a momentum around this energy technology, for which there are implications for the EU.** The international scene sees an increase in support schemes and the development of national strategies for the advancement of fusion energy. In other jurisdictions, governments make use of different support and financing schemes tackling different interconnected objectives, as part of a coherent fusion strategy. To avoid losing its lead and

[58] https://www.energy.gov/science/articles/department-energy-announces-50-million-milestone-based-fusion-development-program

[59] https://www.energy.gov/articles/doe-announces-46-million-commercial-fusion-energy-development#:~:text=This%20funding%20from%20the%20Milestone,from%20the%20sun%20above%20us.

competitiveness, the EU should leverage its scientific position and ITER, and boost funding through new instrument(s) to fill the identified gaps, and support the development of a European fusion ecosystem and speed progress to an EU fusion power plant.

4 AN EU PPP FOR FUSION ENERGY INNOVATION

4.1 EU objectives for Fusion and a Fusion PPP

EU objectives for fusion

It is important that the overarching policy objective of the EC for fusion is defined, as this should also be reflected in the objectives of the PPP and will inform the type of instrument(s) selected. Multiple stakeholders also flagged the need for a clear overarching EU strategy and vision for fusion. The strategy should also be clearly mainstreamed within the long-term decarbonisation path of the EU to ensure it is part of policy thinking. Currently the EUROfusion roadmap[60] (see also section 3.3) is the leading strategy document in the European fusion sector but this is a product of the scientific community, with minor contributions from industry. The EUROfusion roadmap is currently being revised.

The European Commission is currently preparing a strategy that will clarify the objective to assign to a potential PPP to be created. The current report does not wish to pre-empt the outcomes of the strategy but aims rather to nurture the on-going reflection.

For the purpose of this report, as contractor, we have retained as an hypothesis that the overarching objective for the EU in fusion is:

- To build a European Fusion Power Plant that delivers clean, affordable and secure energy [by 20XX], while supporting European leadership in terms of research, innovation and industrial competitiveness.

The pathway to this fusion power plant (FPP) is currently foreseen in 3 main steps, ITER -> DEMO -> FPP, with increasing private sector involvement in each step. Private fusion start-ups foresee their own pathways steps from proof-of-concept device(s) to pilots or demonstrators to their commercial FPP.

Strong political commitment of the European Union regarding the objective for a fusion power plant would have an important signalling effect for the European industry, the investors, the private sector in general as well as the scientific community. This overarching objective would help to give a sense of mission, in a similar way that the Bold Decadal Vision for fusion has in the US. It would also align with criteria for successful mission-oriented innovation, including that it is bold, ambitious and relevant; that there is a clear time-bound measurable direction; and that it is ambitious but realistic[61].

Objectives could have a specified fusion technology focus, noting that there are advantages and disadvantages to selecting objectives around a specific technology focus, i.e. choosing to focus only on magnetic confinement-based approaches. For magnetic confinement there is the clear argument that an exclusive focus would leverage ITER and the strong research and industrial base in the EU. Excluding other approaches, such as inertial fusion, would avoid spreading limited funding too widely – but would run the risk that other approaches may be more successful in the long-term, and could also neglect leading EU industrial capacity specific to these approaches, e.g. optics and laser technology, fuel pellet (target) manufacturing. Implicitly the EU fusion programme is already almost exclusively focused on magnetic confinement based tokamak and stellarator approaches, with little attention to inertial fusion or other novel concepts.

60 https://euro-fusion.org/eurofusion/roadmap/

61 Mazzucato, M. for EC DG RTD (2018) Mission-Oriented Research & Innovation in the EU

EU objectives for a fusion PPP

It will be the responsibility of the Commission to define the primary objective(s) and strategic context of the Public-Private Partnership. While the mandate of the PPP will be in line with the EU policies, the objective(s) of the PPP will influence its design. Depending on the choice of PPP approach the participants can take varying levels of control over setting the specific and operational objectives of the PPP, although it is normal for the EC to retain final decision making authority on approving the objectives. Options for PPPs are explored under section 4.2 with indications on how objectives are set and the role of the EC, industry and the research community in this.

The primary objective of the PPP is crucial, with two key directions emerging for consideration by stakeholders:

- **DEMO as the primary objective:** by specifically naming DEMO as an objective, a PPP would most likely need in the short-medium term to target partnerships between the public research community and engineering and design firms to further develop the conceptual design and other design elements and specifications that can start to happen in advance of necessary data from ITER operation. Amongst existing programmes the UK STEP programme offers the closest parallels for learning as it has started a similar process with industry. The DEMO objective is already strongly reflected in F4E and EUROfusion work, and DEMO focused design activities with industry are already underway. A PPP which is DEMO focused in its objectives could take over this function and role to try to accelerate work on DEMO.
- **Key enabling technologies as the primary objective(s):** given the likely long timelines to DEMO and eventually a fusion power plant, it can be smart to set objectives around the remaining key technical challenges, e.g. addressing common key enabling technologies such as tritium fuel cycle, first wall materials, remote handling etc. This would still be part of an integrated long-term strategy towards a fusion power plant. These would be a logical area of interest for the fusion supply chain, and possibly also start-ups, and lend themselves to a milestone-based programme. A KET focus can also be clearly aligned with DEMO, developing and demonstrating in the short-medium term certain technologies that are necessary for DEMO, but which can also have broader applications and relevance across the fusion industry and possibly other sectors. A PPP on KETs which is DEMO-aligned, but not focused, could work on other areas to complement the existing DEMO work streams ongoing at F4E and EUROfusion, and more effectively engage with start-ups and other private partners, and be more attractive to investors.

The PPP design will also need to consider in its objectives how it intends to address specific issues such as:

- **Retaining flexibility** and adaptability to unforeseen events, potential delays to ITER, funding fluctuations, and shifts in technology focus.
- **Flexibility:** how flexible can the PPP objectives be to events, for example delays to ITER, funding cuts, success of an EU (or other) fusion start-up. Would there be scope for example for a DEMO focused PPP to pivot to a Stellarator design. Given the contrasting potential, of long timelines for ITER and DEMO but also potentially big developments in the short-medium term then it can be smart that objectives have flexibility. Also, recommendations on mission-based innovation put forward an open approach to innovation, where multiple solutions are encouraged bottom-up and some are allowed to fail along the way[62]. This approach is seen in US programmes, but is the opposite of the existing EU approach where the main technological solution has been selected already. Greater flexibility in approaches should be considered in how objectives are framed and specified.
- **Leveraging ITER** and the public and private know-how and experience gained in its construction and assembly both up to now and in-future. The significant investments made in ITER provide an excellent basis for further innovation in many areas, and this may continue in future as further work on ITER is

62 Mazzucato. M for EC DG RTD (2018) Mission-oriented research & innovation in the EU

carried out. It will be an important for a PPP to make the most of this. The PPP should also look to utilise public and private partners in the areas where they are strongest and can complement each other.

- **Coherent development** which ensures that any programme is consistent with other activities carried out in the EU. A clear technology development roadmap or strategic research and innovation agenda should address this. It is not desirable for a PPP to repeat work that is carried out elsewhere in the EU or under another instrument (if multiple instruments are adopted) – therefore an overall alignment is necessary. This could be driven by an EU-level strategic innovation agenda for fusion.
- **Technology transfer:** it is typically a fundamental part of an innovation programme to exchange knowledge between different the research and industrial communities. Within the EU it is understood that there is significant scientific knowledge and expertise held by the fusion research community that could be applied and innovated further by (or with) industry, to the benefit of fusion and industrial competitiveness. An objective on technology transfer could formalise that this is a key goal of the PPP, to bring knowledge from the labs to industry.
- **Start-ups:** the way in which the PPP tailors (or not) its approach to start-ups will also be determined by the objectives set. If it is decided to prioritise DEMO construction as an objective of the PPP this would signal that EU public funding would be unlikely to support fusion start-ups to a large degree if and when they reach a similar pilot/demonstration stage in development. This would hinder the start-up sector in the EU. Whilst an objective targeting start-ups or a more open view on approaches to fusion would lend itself much more to varied forms of PPP support. The US models (ARPA-E, INFUSE and Milestone-based) have been more tailored towards start-ups than the fusion supply chain, implicitly assuming that success of the start-ups will pull supply chain innovation along with them and more easily and naturally attract and access private capital. This also places the start-ups at the head of the private ecosystem, acting as an effective project manager and/or system integrator as well as bringing their own scientific IP. The role of project manager/integrator can also be relevant in a PPP context. The US approach aligns with the mission-oriented principle of a bottom-up, open approach to innovation. However, start-ups primarily focus on approaches with lower TRL levels, are less mature and risk that scarce funding would be spread across multiple approaches, instead of focusing on a single approach.
- **Ecosystem development:** as part of the overarching objective the PPP should contribute to EU industrial and scientific leadership and competitiveness. How should this be reflected in the objectives of the PPP, and to what extent should the design of activities emphasise this aspect.
- **Enhancing cooperation, exchange and skills:** these are all suggestions from stakeholders and valuable for the fusion sector as a whole, particularly for scientific work, but selecting these as objectives for a PPP would also have an influence on the types of activities that should be supported. The Horizon programmes and EUROfusion activities already provide multiple examples of how these objectives could be addressed in a PPP, but perhaps also highlight that these activities could be an unnecessary duplication of existing work (e.g. of EUROfusion), or a distraction from specific goals on technology transfer and key enabling technologies. Stakeholders were clear that international cooperation, whilst essential for science does not make sense as an objective for a PPP with the goal to support EU competitiveness and industry. Only for the UK and other partners to EUROfusion, e.g. Switzerland and Norway might it make sense, but perhaps less so now for the UK after its decision to withdraw from Euratom. However, it should also be noted that the US Milestone program has seen many applicants from US-subsidiaries of non-US companies, similar trends should be foreseen in any EU scheme and appropriate protections put in place.

4.2 Basis for a potential EU PPP for Fusion

It is clear that if the EU wishes its fusion industry to continue to innovate and be competitive in the current and future fusion market that an additional funding instrument is needed and that a PPP instrument is preferred by stakeholders. The analysis of the existing landscape in 3.3 identifies clear gaps in funding mechanisms for industrial innovation in fusion, especially as contracts for manufacturing and other activities for ITER wind-down as it moves to assembly and commissioning. At the same time the analysis suggests a few potential avenues in which a PPP mechanism could be supported in the EU, these include:

1. **Co-Programmed European Partnership (CPEP)** – of the main Horizon Europe research partnership approaches (see section 3.3) these are assessed as the most relevant and interesting for an EU fusion PPP mechanism.
2. **EIT/KIC** – a form of Institutionalised Partnership, it is an alternative option under Horizon Europe, which through its InnoEnergy KIC has already funded one fusion start-up, and could potentially also support industrial innovation in fusion.
3. **F4E innovation partnership-type instrument** – there is scope within the objectives of F4E in contributing to a demonstration fusion power plant and on industrial policy to fund relevant industrial innovation activities, and there is an existing contractual mechanism, an innovation partnership, that could potentially be the vehicle for an EU PPP for fusion.

A completely new instrument could also be considered. For example one option could be for the EC to take on the role of founding a PPP vehicle directly and to create a new PPP structure. Similarly, it could be possible to create a separate legal entity/entities for the purpose of a PPP like the SPRIND programme (DE) and their creation of Pulsed Light Technologies Gmbh to support innovation in lasers for inertial fusion. Such partnership instruments have been created previously under Euratom, including as F4E, but also for the construction of nuclear fission facilities. Alternatively models from the US such as ARPA-E or INFUSE, or from the UK could be directly emulated. **However, we rule out the creation of a completely new instrument** for the following reasons:

- Urgency – creating a completely new instrument would require significant political, legal and other actions and assessments. Given how the European system works the creation could already take many years. Greater speed is needed, the industry cannot afford to wait.
- Flexibility of existing instruments – the instruments highlighted above, especially the CPEP can be very flexible in how they operate. For example there are few practical reasons why calls launched under a CPEP could not take on the characteristics of US programmes such as ARPA-E or INFUSE.

Overall, it is much easier and faster to use an existing mechanism and these still retain many of the benefits that a new instrument could bring. In the opinion of the team this mix of obstacles and possibility to achieve the same using the existing instruments is sufficient to rule out approaches other than the three listed above. In future, for DEMO construction, the creation of a Euratom-specific partnership (see section 3.3) could be considered.

The three main options are further described and analysed below.

Co-Programmed European Partnerships (CPEP)

As highlighted in section 3.3 a Co-Programmed European Partnership (CPEP) is a partnership between the EC and usually private, but sometimes also public, partners (see Table 4-1 below for an indication of industry as a % of members). This approach would therefore accommodate both the industrial and research partners in the fusion community. CPEPs intend to provide the critical mass to pursue innovative solutions that address European or global challenges in a particular field. They should have a life-cycle approach and be limited in time with conditions for phasing out the Programme funding.

A CPEP is agreed through a Memorandum of Understanding (MoU) which sets out the objectives, commitments of the parties and the governance structure for the partnership. A Strategic Research and Innovation Agenda (SRIA) is also developed – typically by the private partners - and agreed by all partners.

Implementation runs through Horizon Europe Work Programmes and calls for proposals. However, in the case of fusion it could be foreseen to create a CPEP PPP under Euratom, whilst still using the Horizon processes as necessary. The partnership, through the SRIA, defines the roadmap and therefore identifies the topics and priorities for which calls are made, although the EC can play an important role in setting or framing the main objectives. These are then agreed with the EC and then published and awarded via Horizon Europe. The calls typically follow a standard Horizon Europe approach, with the basis being grant funding, and where a matching own contribution (of varying proportions) is required. The grant agreement template for Horizon Europe requires parties to agree on treatment of existing intellectual property (IP) organisations bring into work on a call (background IP) and also on how to treat IP created through the work (foreground IP). The main stipulations are that the outputs should aim to be exploited, and that subject to commercial and other constraints, be as open as possible for scientific research. Overall, the specific treatment of IP is left to the consortia to agree between themselves as they bid for a call under the partnership.

Funding for CPEPs is substantial, with hundreds of millions of public funding provided (see Table 4-1) for each existing CPEP. In terms of contributions, the private sector is expected to at least match every euro invested by the EU. These contributions can be in-kind contributions. Private partners in a CPEP are also obliged to carry out additional activities within the CPEP, these should be part of the Strategic Research and Innovation Agenda (SRIA) but not funded by Horizon Europe, i.e. only self-funded, demonstrating a commitment to the innovation agenda (see also 4.3.2 for more detail on contributions).

Table 4-1 Funding of existing CPEPs and indication of industry involvement

Co-programmed partnership	Public funded (Horizon) [M EUR]	Private funded [M EUR]	Total estimated budget [M EUR]	Industry as % of members
Artificial intelligence, data and robotics	1 300	1 300	2 600	Unknown
Photonics	340	Up to 340	680	45%
Clean steel – low carbon steelmaking	700	Up to 1 000	1 700	67%
Made in Europe	Up to 900	Up to 900	1 800	45%
Processes4Planet	Up to 1 300	Up to 1 300	2 600	43%
Connected, cooperative and automated mobility	Up to 500	Up to 500	Up to 1 000	35%
Batteries	925	925	1 850	44%
Zero-emission waterborne transport	530	3 300	3 800	61%
Zero-emission road transport	615	Up to 900	1 230	48%
Built4People	380	400	780	32%

In Horizon Europe, only 5 of the 11 CPEPs were new, i.e. they had no predecessor programme under Horizon 2020.

Within a CPEP partners (both public and private) are always represented to the EC and the Horizon programme by a single organisation. Partners participate in this organisation on a membership basis, with fees from 500 -10 000 EUR/year depending on organisation type and size. The general idea is that this provides a budget to fund the organisation itself, i.e. to provide for a Director General or equivalent and a small secretariat to support them. With an estimate of 50 members paying an average 5 000 EUR/year, this would provide a budget of 250 000 EUR/year to fund such an organisation.

Whilst the EU research community has EUROfusion to fulfil this role, this type of organisation does not currently exist for the private fusion industry in Europe, although the Fusion Industry Association and Fusion Industry Innovation Forum both have some potential to evolve to fill this role.

EIT – InnoEnergy

The European Institute of Innovation and Technology (EIT)'s Knowledge and Innovation Communities (KICs)[63] are nine established, cross-disciplinary partnerships set up by the EU to foster innovation, entrepreneurship, and knowledge exchange within specific topic areas (such as climate change, sustainable energy, digital technologies, health, raw materials, and more). They receive almost EUR 3 billion in funding between 2021-2027. InnoEnergy is the leading KIC dedicated to fostering innovation in sustainable energy technologies and services, bringing together academia, industry, and entrepreneurs to accelerate Europe's transition to a low-carbon energy future. It was allocated EUR 44 million for the two years 2023-2024.

The criteria used for evaluating the types of initiatives funded by EIT KICs, including InnoEnergy, can vary, as there are also different funding mechanisms, which have developed their own programme guidelines and calls for proposals. However, some common criteria and funding focus areas are:

1. Alignment with Societal Challenges
2. Innovation and Novelty
3. Collaborative Nature
4. Market Potential and Scalability
5. Entrepreneurial Element
6. Education and Capacity Building
7. Environmental and Social Sustainability
8. Economic Impact

These criteria align quite well with the stated goals of an EU PPP for fusion to support industrial innovation. Given its potential significance and multidisciplinary nature, a fusion energy category could potentially be introduced under EIT InnoEnergy, to support and accelerate innovation in fusion technologies, research, and commercialization efforts. Currently InnoEnergy has three focus areas on battery storage, green hydrogen and solar PV. Being the EU's main climate innovation initiative, the Climate-KIC could also be suitable given the decarbonisation potential of fusion, but InnoEnergy is likely a better fit.

Under InnoEnergy grant a maximum of 45.55% of costs can be funded, with matching contributions required from partners. These matching contributions can take the form of in-kind contributions. Intellectual property is dealt with in broadly the same way as for CPEPs and remains the property of the company.

EIT-KIC InnoEnergy invested in Novatron Fusion in December 2022, this Sweden based start-up is a spin-out from the KTH Royal Institute of Technology in Stockholm and is pursuing a novel approach to fusion in the magnetic confinement branch, using magnetic mirrors. It aims to prove its concept in a small device currently under construction and then to scale up over the next 2 decades across multiple devices

[63] https://eit.europa.eu/global-challenges/knowledge-and-innovation-communities

to a demonstration power plant. Novatron has raised around EUR 3 million with part funding from EIT InnoEnergy who have also taken an equity stake in the company and have a seat on the board. Feedback from Novatron has been positive on the engagement with InnoEnergy, highlighting the value of the cooperation in addition to the funding, particularly in connecting to networks, providing business advice and linking to investors. We understand that discussions are ongoing between the EC and EIT regarding a role for fusion in a KIC.

F4E Innovation Partnerships

As outlined in section 3.3 F4E has a crucial role in the EU fusion ecosystem, particularly linked to ITER, but also with broader objectives and policies that provide the basis for it to play an expanded role in developing a demonstration fusion power plant in future, in industrial development and possibly in an EU PPP. With F4E employing more than 400 people and having an administrative, financial and technical infrastructure, plus close ties with the industry, it could be well positioned to play a role in a future PPP.

Opportunities have been highlighted where funding could be channelled directly to industrial innovation that supports the objectives of F4E, and as these include DEMO, then the scope of potential innovation covers the full range of key enabling technologies necessary for magnetic confinement based fusion. Model contracts already exist, 'Innovation partnerships'[64] but have not been used to date, as contracting for ITER has followed standard operational or administrative procurement lines. However, these Innovation Partnerships potentially offer the opportunity for F4E to provide grants for industrial innovation. Questions remain, including:

- Over the funding of such grants, i.e. is there sufficient budget available and how spending on these additional activities may be justified, particularly if ITER costs increase.
- Which topics or technology areas would be selected and how?
- How would such a mechanism ensure a partnership?

Indications from F4E suggest that there is budget available, that cannot yet be spent on ITER, yet they would require further mandate from the EC before reallocation to other work, such as these Innovation Partnerships. The choice to do so remains a policy consideration. In terms of topics, a Technology Development Plan is being developed y F4E which would set out the main areas of focus for F4E and which these partnership contracts could target. Finally, whilst the arrangement would be contractual between F4E and the industrial partner, it could also be tendered in a way which ensures that the industrial partner bids in consortium or cooperation with others, including the research community to encourage technology transfer and partnership.

In terms of IP rules the draft contracts suggest that the beneficiary and F4E would take joint ownership, or F4E would at least retain access rights to the outputs of the contract.

Furthermore, industry has expressed concerns that the size, culture and bureaucratic procurement conditions for ITER would make them reluctant to participate in an F4E-led PPP. However, F4E counter that the largest hindrances in the process result from the international cooperation aspect of ITER and the need to share IP with the ITER IO and other partners in the work, and that this would not be as serious an issue in an EU only project.

Comparison

The following Table 4-2 provides a summary and comparison of the three options discussed above, highlighting their key advantages and disadvantages. This shows that all approaches can be positively assessed and could potentially deliver a successful EU fusion PPP arrangement.

[64] https://industryportal.f4e.europa.eu/mainmenu/how-to-do-business/procurement-documents/

Our recommendation is for each of the approaches to be used, as they each address an important need in the funding landscape for fusion innovation and of stakeholders. At the head of the instruments is the **Co-Programmed European Partnership approach**, but this should also be pursued in parallel with: (1) a programme carried out through the **F4E Innovation Partnership instrument**; and (2) **a reservation within the EIT-KIC InnoEnergy to fund EU fusion start-ups**. The F4E approach could potentially be piloted in the short term, particularly if an EU fusion CPEP cannot be introduced before the next Multiannual Financial Framework (MFF) from 2028. The F4E approach could test the general partnership approach and deliver some 'quick wins' for EU fusion innovation. These recommendations are expanded upon in Chapter 5. The remainder of this chapter elaborates on specific aspects of the recommended CPEP for fusion

Table 4-2 Summary and comparison of potential fusion PPP approaches

	Co-Programmed European Partnership	EIT-KIC – InnoEnergy (or similar)	F4E Innovation Partnerships
Advantages	• Significant potential funding available, could fund larger sub-projects • Formalised collaboration between industry, research and EC • Industry taking ownership and lead • Utilises proven existing funding and operational model • Strategic Research and Innovation Agenda jointly developed but aligned to EC goals • Model allows for various types of calls and potential focus areas	• Already active - has funded an EU fusion start-up already • Support to beneficiary is valuable – connecting to networks, investors, advice • Builds on private industry-led ideas • Technology neutral • No need for a fusion vision/strategy, only some budget allocation and potential commercial viability	• Contractual mechanism exists • Flexibility on matching contributions from industry • F4E possess the necessary procurement and technical expertise • Access to industrial network via ILOs • Objectives aligned with EU strategic objectives • Continuity from existing work on ITER • Potential to begin in the short-term

	Co-Programmed European Partnership	EIT-KIC – InnoEnergy (or similar)	F4E Innovation Partnerships
Disadvantages	• Requires matching contribution (time, resource, cash) from industry, at least equivalent to EU contribution • Requires additional activities from industry, not funded by the Partnership • Tied to EU Framework Programme processes which can be slow – unclear when it could be ready to launch, may only be for next MFF • Developing consensus on organisation and research agenda may take time	• Relatively limited funding available, also in competition with other RES under InnoEnergy • Suitability beyond start-ups and SMEs is unclear • Not necessarily aligned with EUROfusion roadmap	• Industry concerns about bureaucracy and repetition of 'heavy' ITER style procedures and F4E culture • Contract-based, which can be risky for industry (risk of not delivering) • Not inherently collaborative with fusion research community, may be unidirectional (F4E-industry) not a partnership • Political risk of spending F4E budget on non-ITER activities
Challenges	• Requires a single organisation to represent the sector (industry & research), this does not yet exist • Possible competition with other Partnerships for candidacy – need for political support in EC • Securing industry commitment to make matching contributions	• Securing sufficient scope for fusion within InnoEnergy • OR Starting a new EIT-KIC could be difficult and time-consuming	• Utilising a mechanism that has not been used • Securing funding within F4E – unclear if available funds would be sufficient • Justifying budgets externally in current ITER delays • Selecting the areas to focus on – can be alleviated with Technology Development Plan (TDP)

	Co-Programmed European Partnership	EIT-KIC – InnoEnergy (or similar)	F4E Innovation Partnerships
Overall conclusion	**Strong positive, albeit with challenges:** whilst this requires the greatest commitment and effort from industry (and the research community), it also provides the best potential in terms of funding, structure, flexibility, profile and focus. There are questions on how quickly this may be created when there is an urgency from the sector, waiting until the next MFF (2028-) would not be ideal.	**Positive, but with limitations:** this instrument offers a potentially effective mechanism to incubate further fusion start-ups, and potentially also SMEs in the fusion supply chain. This could complement a programme which focuses more heavily on industrial innovation on key enabling technologies.	**Positive, but with risks:** this instrument promises the potential to utilise existing structures, capacity and funds to spur industrial innovation in the short term. However, there are risks in the reprioritisation of F4E funding in the context of ITER.

4.3 Specific design recommendations for an EU Co-Programmed European Partnership for fusion energy

A **Memorandum of Understanding (MoU)** is created as the basis of a Co-Programmed European Partnership, this typically sets out the:

- Objectives of the PPP: the general, specific and operational objectives of the partnership
- Contributions and activities of the partners
- Governance arrangements
- Roles and responsibilities of the partners: covering the activities and commitments of the European Commission and all other partners – including commitments to openness and transparency, dissemination and communication and coherence with other partnerships
- Monitoring and reporting – including on which in-kind commitments are allowed and how these are monitored, and KPIs
- Administrative issues – on the application, duration and review of the partnership

Furthermore, a **Strategic Research and Innovation Agenda** is developed by each CPEP which defines the specifics of their work programme and goals.

We address specifics for a wide variety of these issues, and others relevant for the partnership in the following sections. However, it should be noted that the specifics of the partnership should evolve and become clearer along the CPEP design process, this will clarify the roles and responsibilities of partners, the structure of the partnership, how decisions are taken at all stages.

4.3.1 Setting the objectives and strategic research and innovation agenda (SRIA)

The objectives for a PPP in fusion were discussed in section 4.1. For a CPEP for fusion innovation we recommend that the objectives are centred on advancing Key Enabling Technologies (KET) for fusion and developing industrial innovation and competitiveness.

To achieve these objectives the new PPP CPEP should develop a **Strategic Research and Innovation Agenda (SRIA)**, as a first milestone. The SRIA will establish the key research and innovation areas that are currently considered to be crucial, and where the industrial and research community working in partnership can tangibly accelerate progress. The SRIA should be part of a broader fusion strategy for the EU, aligned with the work that EUROfusion and F4E and others will be carrying out. The SRIA is very important to the partnership as it not only sets the basis of the calls to be issued for the partnership, but it also sets the specific and operational objectives of the partnership, the priorities and division of funds between the calls, and defines the key performance indicators to be tracked for monitoring and evaluation. The development of the SRIA needs to involve all key stakeholders in the partnership and will be one of the key steps in the development process.

The preparation of a fusion SRIA can draw upon the established EUROfusion Roadmap[65] (currently being updated) which provides a sound basis for a Roadmap towards a magnetic confinement tokamak-based fusion powerplant and from which many points could be adopted directly, e.g. on prioritisation of key enabling technologies. However, the EUROfusion Roadmap should not be the pre-determined SRIA of the partnership, as this was developed with only minor industry input and it also represents a quite closed pathway to fusion which discards other potentially valid options. The Technology Development Programme (TDP) being developed by F4E may also provide a basis for part of the SRIA on the magnetic confinement pathway.

The SRIA should be coherent with the EUROfusion Roadmap and F4E TDP to avoid duplication and ensure that the right instruments and parties are working in their most effective areas. Coherence means also taking into account other ongoing work in fusion e.g. in the context of IFMIF-DONES then certain tasks on neutron sources or materials may not be necessary to address within the PPP, similarly with divertors and DTT.

A potential process for the SRIA development could be:

- **EC sets main objectives:** The EC (based on advice from EUROfusion, F4E and political direction) decides on the overall strategy and objectives for fusion, which instruments will be used to support it and how much can be made available.
  - ☐ Using the EUROfusion roadmap and the F4E TDP a workplan and division of focus areas and tasks is made.
  - ☐ Including proposals for which parts of the overall strategy should be addressed by the CPEP and which by the other instruments. This could be done by the EC or by an independent party. It is not recommended to let one of the potential beneficiaries carry this step out on its own as this would bias the recommendations and affect the subsequent stakeholder discussions.
- **Stakeholder process to discuss, refine and add detailed objectives and milestones:** A short stakeholder process is initiated – potentially via the FIIF or F4E roundtables, but with an expanded audience of all parties - to introduce, discuss and refine the focus areas, milestones, allocation and various other elements. This process can also be used to establish the leadership group and core membership of the partnership.
  - ☐ The process could also create working groups for each priority area to look into each at a deeper level of granularity, looking at the concrete steps and milestones that could be defined as the basis for calls under the CPEP, with an eye at what could be realistically achieved and what level of funding may be needed. However, the broad lines should be agreed relatively early to allow the process to move forward.
  - ☐ This step would produce a detailed final SRIA response from stakeholders.

[65] European Research Roadmap to the realisation of Fusion Energy

- **EC iteration, validation and approval:** as a final step the EC would review the SRIA response and following up with stakeholders would reach an agreed final version of the document as the basis for the partnership.

In terms of content, given that the fusion SRIA would be the roadmap[66] (or technology programme) of the fusion PPP, it should **ideally comprise the following** elements:

- An introduction presenting the main stakeholders having contributed to the SRIA, and that are part of the value chain. This could be extended to describe the basics of the fusion ecosystem in Europe;
- An explanation of how it intends to build Europe leadership in fusion, building on existing expertise and knowledge. It should also provide a short state-of-play, summarising the research and innovation done so far in Europe, and globally;
- A reminder of the common vision and technological scope for fusion in this specific PPP, its strategic objectives (i.e. its general and specific objectives on the short, medium and long term), and its operational objectives;
- The identification of the needed investments in fusion R&I, and their expected impacts;
- A thorough description of the R&I Areas, tackling the maturity level of the main technology components, and the research needs. It will comprise a projection of the delivery timescales, balancing the specific need for a component to achieve fusion energy and a realistic research progress to allow its realisation;
- A description of its implementation, looking at the activities and resources required, including the partners contribution. It will define the complete governance structure, the different bodies, memberships rules, roles and responsibilities, and the functional targets of the PPP;
- A description of areas in which additional activities will be carried out by the partnership;
- A next steps section, setting out how the Roadmap forms the basis for regular work programmes, their funding and implementation. It should also tackle the updating process of this SRIA, which is supposed to pave the way until 2035 at least;
- Setting out further details on coherence and collaboration with other European Partnerships, synergies with other Union programmes, Union bodies and national, international, and intergovernmental programmes and policies, and the relevant parts of Horizon Europe.

Technology focus

In developing an SRIA for the CPEP ideally the number of R&I areas should remain limited, to avoid spreading limited resources too thinly and losing focus. In our opinion the priorities should be two fold:

(1) **A focus on key enabling technologies towards a fusion power plant** and assessing in which areas the partnership would be most suited to contribute – these should be magnetic-confinement and DEMO aligned, but wherever possible also address other approaches, e.g. materials relevant for all kinds of fusion. These should also be for technologies that have commercialisation possibilities in a timeframe of up to 8 years, which is necessary to induce the required levels of industry investment and contributions – this was a point made clearly by industrial stakeholders in various discussions;

(2) **A focus on high-risk but potentially high reward activities outside the main magnetic confinement tokamak pathway** – being a priority request of the fusion start-ups, but also aligned with mission-oriented innovation best-practice. The rationale being, that whilst DEMO may be the lowest risk pathway to fusion (albeit still high risk) it will take a very long time, therefore the EU should also be open to higher risk pathways that could potentially offer faster routes;

We recommend a 75:25 split in focus between these priorities, this ensures the largest part of the work is DEMO-aligned but still with broader appeal for the fusion supply chain. The smaller share nevertheless

[66] An good reference can be found in the Battery SRIA, available on https://bepassociation.eu/wp-content/uploads/2021/09/BATT4EU_reportA4_SRIA_V15_September.pdf

provides a funding mechanism for the EU to explore higher risk innovations, which assists its start-ups to scale up and avoids putting all its eggs in one basket.

Without wishing to pre-determine any choices for the (75%) DEMO-aligned priorities, as further discussion and technical elaboration will be needed in any case, we present below in Table 4-3 a list of potential priorities for key-enabling technologies on which to focus. In Annex E we also provide a detailed analysis of key enabling technologies from the US perspective.

Table 4-3 Proposed allocation of KETs between the CPEP and other instruments

CPEP – KETs with commercialisation possibilities in short-medium term	For other parts of the fusion programme (F4E Innovation Partnerships, EUROfusion) – KETs with limited commercialisation possibilities in short-medium term
• Magnets (HTS manufacturing) • Heating systems (neutral beam, gyrotron/cyclotron) • Maintenance (remote handling) • Neutron tolerant materials (first wall, structural) • Cooling (cryogenics) • Power extraction • Diagnostics and software	• Plasma regimes of operation (plasma science, control, codes) • Tritium self-sufficiency (fuel cycle, blankets, control) • Heat exhaust systems (divertors) • Integrated design and engineering • Modelling and simulation • Safety (neutronics, radiation)

For those intended to be covered outside the CPEP, the rationales include:

- Plasma regimes to be addressed through EUROfusion work on JET, ASDEX-U, WEST, JT-60SA, W7-X and other devices.
- Tritium self-sufficiency – remains at a low TRL so that further research is needed before it can move to industrial development, plus it also has limited commercialisation possibilities outside fusion.
- Heat exhaust systems – work at DTT could address this aspect.
- Integrated design and engineering – this is primarily for DEMO and is at an early stage, work on this can continue to be led by EUROfusion (and possibly more involvement of F4E), contracting industrial partners as needed
- Modelling and simulation – is primarily scientific work that needs access to research devices and computing infrastructure.
- Safety – remains a relatively distant need, and greater EU regulatory certainty is needed before further work on this area.

These items could be addressed via the proposed F4E Innovation Partnerships, or through EUROfusion and existing programmes where mentioned. However, this assessment is not intended to be final and should be reviewed and updated as part of the process of establishing the CPEP, i.e. there could be activities on either side of the table that could be well addressed on the other side. This prioritisation should also reviewed and updated periodically once the CPEP is established.

For the high-risk pathway (25%), in addition to the labelled KETs for the CPEP, plasma regimes (for proof-of-concept) and modelling and simulation activities should also be considered under the CPEP.

4.3.2 Governance

Membership

Membership of the partnership should consist of representatives of the industry, start-ups and of research organisations. The participation of innovation and technology bodies or platforms should also be considered. The representativeness of the partners needs to be clear, and should respect several overarching principles (e.g. balance between corporates and SMEs; geographical distribution, alignment with technological priorities). The partnership should be a forum for dialogue between partners, to ensure smooth cooperation and communication.

Membership should be on paid basis, with a small contribution from each member funding the operations of the secretariat of the single representative organisation for the partnership. As highlighted earlier, annual membership fees of between EUR 1 000 and 5 000 are normal.

Roles and responsibilities

This section describes what the activities and commitments of each partner could encompass, in general terms:

- **Industry**
  - ☐ **Contributing to define the SRIA**, or identify priorities of research and innovation activities, and define call topics;
  - ☐ Making their in-kind activities and investments to **contribute** to the PPP;
  - ☐ The industry should also have a disseminating role, communicating its activities and results broadly, to contribute to the global fusion agenda;
  - ☐ The industry should set up and maintain a clear strategy and plan for additional activities under the terms of the CPEP, and also plan joint activities with other relevant European Partnerships and research activities.
  - ☐ **Representing the industry**, a representative organisation would be highly beneficial to participate and collate the inputs of industry in the required discussions to create a CPEP. Creating such a group would likely be beneficial on its own for the industry. Two groups have been identified that could be the basis of this organisation:
- **Fusion Industry Innovation Forum (FIIF)** this small advisory group meets around twice a year and includes representatives from the supply chain industry, research and the EC. It does not include any start-ups and the membership is quite ITER focused and small.
- **Fusion Industry Association (FIA)**, is the main industry association for fusion globally, and whilst the EU fusion start-ups are all members, it has a quite US-centric focus. Its primary focus is on fusion start-ups, although supply chain companies are also affiliate members.
- Either of these could be the basis for the industry grouping (effectively an EU industry trade association), for example if the FIA appointed an EU Director, similar to the UK Director they appointed in 2023, and with a focus broader than start-ups; or the FIIF if it brought onboard a broader membership, including start-ups and became more active.
- **Note that this industry grouping would not be the same as the CPEP lead**, which should also be created, as the CPEP lead needs to represent all members (including research), and would not carry out activities such as lobbying and other activities which are normal for an EU industry association.
- **Laboratories and research organisations**
  - ☐ More or less they should have the same roles and responsibilities as the industry.
  - ☐ Laboratories and research organisations should also be represented by a single organisation or association. **EUROfusion** already fulfils this role, and it is recommended they continue, with a focus on how to create synergies and complementarities between the research activities and funding for

the industry, and to identify opportunities for technology transfer and exchange with EU industry. However, individual labs may also wish to play a role in the CPEP organisation.

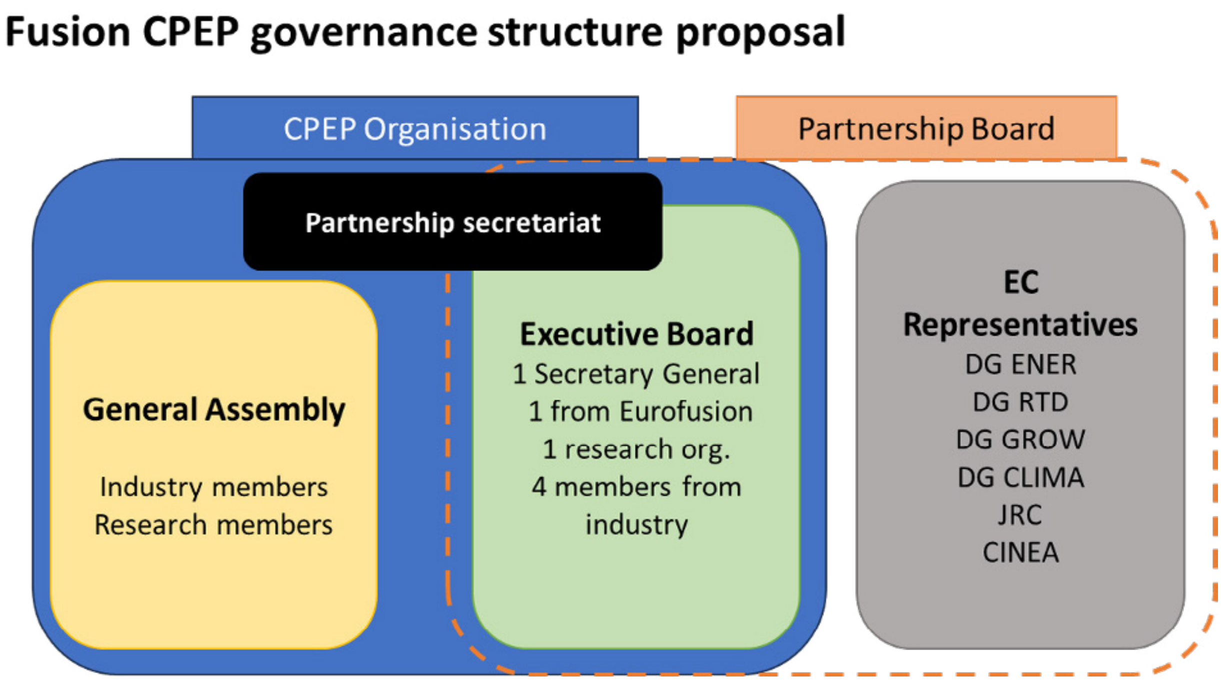
- **European Commission**
  - ☐ Taking into account the input and advice from other partners when defining the SRIA, or when identifying call topics for research and innovation activities;
  - ☐ Maintaining a regular dialogue with partners;
  - ☐ Supporting and contributing to a regular monitoring of the PPP implementation and results;
  - ☐ Evaluating added value, effectiveness, efficiency, openness, transparency and relevance of the activities. Evaluating their complementarity with national initiatives.
  - ☐ It could be foreseen that **F4E** carries out part of this role on behalf of the European Commission, particularly monitoring and administrative activities related to the calls, although some industry may perceive this a conflict of interest and prefer an independent evaluation team.

Structure

We would propose a structure similar to the following (see Figure 4-1) for the CPEP for Fusion. With industry (and the research community) represented by a single organisation (CPEP Organisation). This would be led by an **Executive Board** which is made from representatives from industry and the research community. One of the Executive board members, or an appointee, could act as **Secretary General** and as lead of the **Partnership secretariat** perform, with support of a small staff as necessary, the day-to-day running of the association representing the private parties and running the partnership. We recommend a maximum of 7 board members, including the Secretary General. Larger groups would make decision processes longer and more difficult, particularly when, aside from the Secretary General, the board members would carry out this role in addition to their normal duties. For the Executive Board composition we would recommend a weighting towards industry, either 4:3 or 5:2, to ensure that there is sufficient commercial focus in the activities. EUROfusion would be well placed to represent the research community, alongside a rotating representative(s) of leading research institutions as decided within the research community.

The **General Assembly** would include all subscribed (paying) members of the partnership from industry and research, who would input to broader discussions and inform the Executive Board of their needs and views, and from which working groups may be formed at the request of the executive board. The CPEP partnership board would be formed by the combination of the Executive Board from the private side, and delegates from the EC, these may also include F4E as appropriate.

Figure 4-1 Proposed governance structure of fusion CPEP



Process

The process to establish a CPEP for fusion should begin with some urgency if the possibility to begin in 2025-2027 is to be achieved. Establishing the representative organisation for the Partnership will be crucial, combining EU industry and research stakeholders. A process to support the organisation and formation of such an EU representation should be prioritised, and this should also address the lack of a fusion industry representative group which would likely need to be a first step in this process.

Taking the example of the US and the formation of the Fusion Industry Association (FIA) in 2018. In 2013, the DOE Advanced Research Projects Agency-Energy (ARPA-E) started to formulate its first fusion program ALPHA. The FIA was an outcome of conversations that occurred during ARPA-E (ALPHA) annual fusion meetings (2015–2018). This was feasible thanks to the fact these meetings became a popular venue not only for ARPA-E fusion teams but for many privately funded fusion companies, even if they were not receiving ARPAE funding[67].

This shows that networks through existing programmes and activities can be used as a basis to accelerate the creation of representative organisations. In the US this happened rather organically over time, in the EU, this may need to be expedited. A Collective Support Action which supports stakeholders to come together towards this purpose could be useful given the urgency. This approach has been used in some sectors already such as for the European Quantum Industry Consortium (QuIC). The process presented by the Batteries partnership at the stakeholder workshop is also informative of the urgency, time requirement and political dimension to the partnership discussions. Taking one of the examples the EC could plan to launch a platform or a forum to engage the dialogue with the industry and research institutions, similarly to the launch of the European Technology and Innovation Platform (ETIP) Batteries Europe in 2018. Such a platform could also work to bring the fusion industry and research community together, but this may be too time consuming.

[67] Hsu, S (2023) US fusion energy development via public-private partnerships, Journal of Fusion Energy, 42, 12

Leveraging existing organisations, networks and processes is recommended to accelerate the formation of the CPEP organisation. As noted above the FIIF and FIA both already provide a potential basis of organisation for the fusion industry. Perhaps the former is better placed to evolve towards the CPEP lead organisation whilst the latter is better placed to evolve towards the European fusion industry trade association, subject to the adjustments noted in the Roles and Responsibilities sub-section, including appointment of an EU Director. In any case, increased discussion and cooperation between the two should be part of the process. A further additional branch to the process is to leverage the existing events and networks via F4E, the various annual events and roundtables, and the Industrial Liaison Officer network can each be valuable to access and convene the network of EU industry.

4.3.3 Contributions, ownership and activities

Funding and contributions

As shown in 4.2 all co-programmed partnerships provide own funds that are either matched or higher than the public contribution, and that the public contribution has been in the range of EUR 340m – 1 300m over the 2021-2027 period, or roughly EUR 50 – 185 million per year. This arrangement is broadly equivalent to the basis on which EUROfusion, a co-funded European partnership, already works, with Euratom providing 55% of the funding and 45% matching funds provided by the consortium members (via their national governments). Given the scale of what needs to be achieved in fusion and the first-of-a-kind and engineering heavy nature of many key enabling technologies, then aiming for funding at the higher end of this range would be preferable. For comparison in the US the Milestone-based programme has funded USD 46 million (around EUR 42 million) in its first round, with up to USD 415 million (EUR 375 m) reserved over 5 years (e.g. EUR 75m/year) in the CHIPS and Science Act. Whilst the EU should not just follow the US, these amounts provides a benchmark for the level of funding others see as necessary to advance in fusion. The SRIA should also be used to scope the level of funding needed in each priority area to make progress towards the objectives.

One issue for funding and the required matching private contribution is that due to the high level of risk involved and the lack of a business case in the short or medium term, companies in the supply chain do not view many areas in the sector as being commercially mature, and are reluctant to invest their own resources. This is particularly important for SMEs, and even for larger firms where committing large amounts, e.g. >EUR 1 million, could be difficult to justify. Therefore, considering the role of start-ups and their investors can become important. For example a start-up could potentially act as a project integrator/co-ordinator to lead a consortium on KETs, and bring in additional private investment to expand the size of the projects possible under the CPEP. The consortia would need to include research and industry partners in any case as the start-ups do not have the in-house capabilities to manufacture components for demonstration, nor all the scientific expertise.

In the current EU framework, within the CPEP model the contributions must be at least 50:50 between the EU and the partnership over the full course of its operation. However, the calls which are part of the CPEP can take the form of Research and Innovation Actions (RIA) or Innovation Actions (IA), for which up to 100% and 70% EU contributions can be made depending on the organisation type, i.e. non-profits default to 100%. The form will depend on the TRL level, e.g. RIAs apply at lower TRLs. Therefore, at the individual call level the matching contributions from the partners can be lower than 50%. However, these must be compensated over the duration of the partnership by ‘additional activities’ carried out by the partners, without matching EU contributions, which bring the overall contributions of the partnership in line with those of the EU. These “additional activities” should directly contribute to the topics of the SRIA, even though they are not part of the calls.

The contributions of the industry and research partners within both calls and additional activities typically take the form of in-kind contributions in staff time, supporting infrastructure, resources and other costs the company incurs in its work on the Partnership or in parallel and can include e.g. ongoing research & development, assuming it contributes to the SRIA topics. For the additional activities, the in-kind contributions should be dedicated towards activities that align with the goals of the partnership, as defined and agreed in the SRIA and an additional activities plan agreed with the EC. These primarily include further research and innovation, and demonstration work, but can also encompass other activities such as education and training. The in-kind time and resources that organisations dedicate to additional activities such as these, can be counted as contributions additional to those specific to the calls and are used to ensure a 50% matching contribution for the CPEP as a whole. The additional activities allow for the overall match funding to be achieved, whilst allowing for higher than 50% public funding in specific calls.

The financial resources should be allocated based on an agreed SRIA, with a clear prioritisation among the research activities. Payments should be arranged upon verifiable completion of milestones (reducing cost-accounting administrative burdens and enabling greater risk tolerance by shifting more of the financial risk to the private sector).

Intellectual property rights (IPR)

The aim of the partnership is the development of know-how, technologies, solutions and commercial products and services, which include intellectual property (IP) components to manage, especially when it is developed jointly by several entities. Therefore, intellectual property management should still be considered as a key aspect for the partnership and will need to be addressed already within the MoU and SRIA. This should ensure the right balance between risk and incentives for the industry and research participants, i.e. that the level of risk taken on (e.g. in providing own contributions, sharing existing IP) is also reflected in the treatment of IP generated by the partnership, and that the greater the public funded share, the more open and accessible the outputs should be, and vice-versa as industry contributions increase, so should their exclusive rights to IP.

Good IP management relies on the proper distribution and acknowledgement of the rights of consortium members. This includes both the existing IP of consortium partners (IP background) or those that result from the project execution and that might be of exploitable interest (IP foreground). The aim is to avoid potential inconveniences, delays and conflict that may occur while using and exploiting the technology and knowhow provided and generated during the project.[68]

Rules regarding the management of intellectual property have emerged as a critical element to consider in the design of a PPP. Based on the review of existing schemes, no standardized approach can be identified. In the majority of PPPs in the US and UK with a focus on fusion, the ownership of the IP on the findings (IP foreground) remains with the private entity generating them. In these cases, the public partner can access the findings protected by the IP agreement on a royalty-free basis. In the EU, the approach adopted by F4E in its contracts distinguishes between background and foreground knowledge (this is the rule applied by the EC more generally in Horizon Europe, see below). Given that the aim at this stage is to get industry engaged, it would be advisable to set IP arrangements at least partially in favour of industry. This has been identified as a success factor in other programmes, for example in the NASA COTS programme[69]. This would therefore take the form of standard (non-negotiable) IP contracts for all institutions to sign up to as part of PPP funding applications, accelerating project initiation.

However, it remains important to acknowledge that while the IP would be owned by the private sector, some level of sharing or access would be required given the role of public funding, and particularly the legal requirement that public funded institutions should not give away IP without some form of

68 https://idconsortium.com/recommendationsip/intellectual-property-management-in-european-funded-projects

69 NASA (2017) Commercial Orbital Transportation Services (COTS) Lessons Learned for Commercial Capability Development Partnerships

recompense. This recompense could include enabling scientifically relevant outputs to be published by research laboratories in order to benefit the scientific fusion community. Open access to scientific publications and research data is one of the standard conditions of Horizon Europe participation (under Article 39), subject to a general principle of 'as open as possible, as closed as necessary'.

For projects funded by the European Commission, a contractual document (Grant Agreement or GA) defines the terms and conditions regarding the Intellectual Property[70]. This document deals with the rights and obligations between the beneficiaries themselves, applying to all partners. The main aspects addressed by GA are the following:

Items / topics	Applicability to Fusion
Agreement on background- The beneficiaries must identify and agree on the background for the action ('agreement on background'). To exercise access rights, this must first be requested in writing ('request for access'). Unless agreed otherwise, access rights do not include the right to sub-license.	Directly applicable to fusion, as basic rule
Access rights for other beneficiaries – the beneficiaries must give each other access — on a royalty-free basis — **to background needed to implement their own tasks** under the action, unless the beneficiary that holds the background has — before acceding to the Agreement —: informed the other beneficiaries that access to its background is subject to legal restrictions or limits, including those imposed by the rights of third parties (including personnel), or; agreed with the other beneficiaries that access would not be on a royalty-free basis.	Directly applicable to fusion, although it would require strong confidentiality rules
Ownership by the beneficiary that generates the results – Results are owned by the beneficiary that generates them	This is a crucial provision for fusion start-ups and likely also for industry
Joint ownership by several beneficiaries- The joint owners must agree on the allocation and terms of exercise of their joint ownership ('joint ownership agreement'), to ensure compliance with their obligations under this Agreement. Unless otherwise agreed in the joint ownership agreement, each joint owner may grant non-exclusive licences to third parties to exploit jointly-owned results (without any right to sub-license) under fair and reasonable compensation. Once the results have been generated, joint owners may agree (in writing) to apply another regime than joint ownership	This might become complex, in case research and industry are partners

[70] https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/agr-contr/unit-mga_he_en.pdf

Items / topics	Applicability to Fusion
Obligation to protect the results - each beneficiary must examine the possibility of protecting its results and must adequately protect them — for an appropriate period and with appropriate territorial coverage — if: the results can reasonably be expected to be commercially or industrially exploited and; protecting them is possible, reasonable and justified. When deciding on protection, the beneficiary must consider its own legitimate interests and the legitimate interests (especially commercial) of the other beneficiaries	This seems to be less critical for fusion
Agency ownership, to protect the results – If a beneficiary intends not to protect its results, to stop protecting them or not seek an extension of protection, the Agency may assume ownership to ensure their (continued) protection	Idem

In Horizon Europe, the ownership and joint ownership rules are the default practice and thus different arrangements can be reached contractually. It is therefore possible to decide that all results will be owned by everyone jointly, either in the MoU of the partnership, or by the consortia which are formed to bid for the calls within their individual consortium agreements, or by way of later agreements (IP Helpdesk). Alternative distribution of rights can also be agreed by the consortia, but typically there is an obligation to exploit the generated outputs with a four-year period otherwise a process begins which looks at alternative means to open the outputs for exploitation, e.g. through licensing, granting access rights or transferring ownership.

As noted at the start of this section the basic principle in dealing with IP should take a progressive approach, with ownership and access linked to contributions. This is driven by the currently low level of maturity and consequently the lack of a business case, but at the same time the large funding needs to further develop fusion. It should be progressive to adapt as higher TRL are reached. This would also help to set a basis for agreement in future when the capital needed to achieve the new milestones towards a demonstration plant will increase from EUR million to EUR billion. The development of the SRIA should already have taken into account the TRL and commercialisation possibilities of the work prioritised under the CPEP which helps to determine the type of IP rules that should normally apply.

Activities to be funded

The specific activities would be decided by the partnership itself once active, but we would recommend to adopt milestone-based activities. This is consistent with existing Horizon Programmes, good practice in other fusion PPPs globally and also the preferences of stakeholders. In setting milestones, these need to:

- Be achievable but also stretch participants to invest and innovate.
- Be meaningful in the context of the Strategic Research and Innovation Agenda.
- Be set with strong inputs from technical and scientific experts representing the public interest, not only by private participants themselves.

The activities should be structured step-wise around the selected goals, for example in progressing a key enabling technology to a particular TRL level. Depending on the need then different types of calls could be issued, from innovation partnership projects between industry and research as the core type, but also including technology transfer type projects (similar to INFUSE in the US) or other types of calls.

Lessons from processes to design and evaluate calls

The SRIA forms the basis for the regular work programmes (we recommend on a 3-year basis), which would advise on the calls to be launched via Horizon Europe. The Horizon Europe process already provides a basis on how the calls can be organised, however, there are some specifics to the partnership and evaluation criteria that can be taken into account based on experience in other programmes.

Independent review is important. The SRIA will have defined the calls and key milestones to be achieved. Consortia bidding for the work will require their applications to be assessed. Section 2.3.3 provides some advice on potential evaluation criteria, in case the existing process needs to be tailored. Given that the research community should be directly involved in the partnership itself there could be a conflict of interest in using these experts for independent review. There are a few ways to address this problem: (1) using F4E, as they would not normally be a member of the CPEP then they could play part of this role, which is something they are familiar with from existing procurement processes; (2) additionally independent consultants or international experts could be employed to support the assessments if the scientific knowledge of F4E is insufficient. This approach has been used successfully in the US Milestone-based program. The role of these experts should be to ensure that the aims and milestones set within the calls are meaningful, sound from a scientific and/or engineering perspective, stretching (not too easy) and aligned with the SRIA objectives.

Consideration should be given to whether calls require consortia with specific characteristics, i.e. that they must include groups from X different Member States, that they must include both industry and research partners, that SMEs should be involved, and the eligibility of non-EU participants should be addressed. In our opinion it would be wise to specify that both industry and research partners are included in any application, this should happen organically in any case, but would help to ensure the desired technology transfer and exchange from the partnership. Programmes in the US have allowed participation from non-US headquartered companies, but those have required US subsidiaries, similar rules should be reviewed for an EU programme, perhaps with special consideration for non-EU partners (e.g. CH) which are still within Euratom and which can bring valuable industrial and research contributions.

Communication and dissemination

The main objective for the dissemination and communication of information is to spread the information, results and impacts delivered by the CPEP activities among the stakeholders. The dissemination and communication should also support opportunities to involve the civil society and enhance public awareness, helping to build a positive image of fusion, raising awareness and keeping it distinct from fission. A commitment to this will be an important part of the MoU of a partnership.

The strategy should include information sharing through website and newsletters, knowledge sharing among partners, coordinated outreach activities and jointly organised conferences and events together with the European institutions and various stakeholders including civil society representatives.

Within the Governing Body, it is the role of the 'Programme Office' or a 'Communication Team' to support coordination and communication activities, measures and reports on KPIs and organise events to promote the Partnership.

Risk mitigation

Within the CPEP reserve funds should be kept aside, which could be made available in extreme circumstances. This would help to mitigate risks that were not previously anticipated which are particularly relevant in first-of-a-kind research innovation. For calls involving the assembly and demonstration of devices or equipment, unforeseen risks might emerge that need to be mitigated using reserve funds. These funds should only be utilised to mitigate risks once the partners have made significant progress.

The purpose of the reserve funds is to drive down residual risks as demonstration nears, instead of gradually tapping into the reserve. If they are deployed too early, partners may not recognise the ideal place to use them, and if they are deployed too late, there may not be enough time to properly utilise them in the programme flow.[71]

4.3.4 Monitoring and Evaluation

Coherence and cooperation with other partnerships

It is key that the partnership ensures coherence with other EU strategies, policies and objectives, and that it builds cooperation with other partnerships. Within Co-programmed partnerships, the practice is for partners to set up a clear strategy for the interfaces and joint activities with the other relevant European Partnerships, as well as with the broader European research and innovation system and communities. In this regard, the MoU further identifies specific Union partnerships with which to establish a formal and regular collaboration. Moreover, each partnership's SRIA sets out details on coherence and collaboration with other European Partnerships, synergies with EU programmes, EU bodies and national, international, and intergovernmental programmes and policies, and the relevant parts of Horizon Europe. Goals of such cooperation include:

- Fostering strategic collaboration;
- Establishing formal collaborations;
- Leveraging synergies with complementary partnerships;
- Emphasizing enabling technologies;
- Supporting mission alignment;
- Engaging with industry and technological initiatives.

Leading candidates for cooperation include:

- High Performance Computing – to support simulations and plasma control;
- Artificial Intelligence, data and robotics;
- Made in Europe – for advanced manufacturing.

Coordination with initiatives taken at national level is crucial, to support the agenda of the PPP and/or to maximise the impacts of the results.

KPI monitoring and reporting[72]

The CPEP should be subject to continuous monitoring and periodic reporting in accordance with Article 50, Annex III and Annex V of Horizon Europe. The outcomes of such monitoring practices are used to feed into the evaluations of the partnerships for Horizon Europe. This procedure is streamlined for both the EU and non-EU parties, and covers the following information on work progress:

- The **progress of the partnership towards its objectives based on its KPIs** and the expected scientific, economic and societal impacts;
- Information on the **functioning of the Partnership,** including synergies and collaboration with other partnerships
- **Investments in operational activities** undertaken by the partners other than the EU

71 COTS lessons learned report https://www.nasa.gov/content/cots-lessons-learned-report-0/

72 https://www.era-learn.eu/partnerships-in-a-nutshell/type-of-networks/co-programmed-european-partnerships/clean-steel_low-carbon-steelmaking_mou.pdf

- Structured and **representative "impact case studies**" that will be used to highlight lessons learned from specific projects/activities, their drivers and barriers to impact and their possible follow up with the appropriate instruments.

The Partners commit to establishing and implementing an efficient reporting and monitoring system for the oversight of general systems. This system will enable both the Co-programmed Partnership and the Commission to track the progress made towards the stated objectives and impacts over time, as well as to gather implementation and management data. The provided information will encompass various aspects, including:

- **Comprehensive details about the calls for proposals in the Work Programmes**, including information on received proposals, granted funds, beneficiaries, participants, and the individual projects' results and overall progress towards achieving impact…
- **Updates on the activities and contributions of the Partners**, excluding the EU, along with their progress towards objectives, deliverables, and key performance indicators (KPIs). It will also cover their visibility and positioning in the international context, the achieved results, impacts, and the leverage obtained. The primary method of collecting this information will involve annual and biennial reports from the Partners, excluding the EU, and utilizing the Commission's reporting systems or the management of the Horizon Europe programme.

Acknowledging the value of a structured, streamlined approach to KPI monitoring and reporting, we suggest for this method to be adopted by a PPP on fusion energy. It is crucial to identify early on the short and medium term objectives of the partnership, which can be used to track progress in a formal manner. The milestone-based approach to projects under the programme lends itself towards effective monitoring of progress. The availability of these standardized approaches makes the case for their adoption in the framework of a fusion partnership.

Risk management

Risk is identified as a key critical dimension of a successful partnership. As a way to mitigate and address risks encountered by all partners, Co-programmed partnerships include several monitoring mechanisms to follow the development status of the objectives to recommend adjustment of research priorities and activities according to changing markets or policy orientation. In Co-programmed partnerships, a Monitoring Group is established to ensure the common vision of the partnership is pursued by both the private and public members. Below, we provide an overview of how risk management is addressed, from an organizational perspective, in the Clean Steel Partnership:

- **Public side:**
  ☐ European Commission DGs: DG-RTD and DG-GROW.
  ☐ European Commission's Executive Agencies: European Health and Digital Executive Agency ("**HaDEA**") and European Research Executive Agency ("**REA**").
- **Private side:**
  ☐ The European Steel Technology Platform ("**ESTEP"**).
  ☐ The five Technical Groups Steel ("**TGAs**") in the Research Fund for Coal and Steel ("**RFCS**") program.

Taking knowledge of this existing risk management system within Co-programmed partnership, we recommend to extend it to the PPP on fusion and adapt to its stakeholders. In particular, we propose to establish a similar **Monitoring Group**, comprising the relevant Commission bodies and DGs for fusion, which would a priori involve DG ENER, DG RTD, DG GROW, and other Commission Services as relevant, as well representatives of the industry and research organisations. The presence of all relevant stakeholders in the monitoring ensures the fair representation of all, while guaranteeing constant exchange between them on key issues of risk. On the private side, while no organization currently exists that brings together fusion industry as a whole, before perhaps such a body will emerge, a body comprising representatives from the consortium will fulfill this role. Finally, to the extent that this is welcome from the partners, the establishment of a similar mutual insurance mechanism seems an effective means to **manage financial risk**, particularly from the private perspective. Nonetheless, as it emerged prominently from several stakeholder interviews, risk management depends heavily on the specific contractual negotiations between the parties, and we therefore expect such negotiations to take place at the onset of this PPP as well, addressing all matters related to the parties' risks mitigation strategies.

4.4 Supporting frameworks

A handful of other issues were flagged for attention during the work. Whilst not directly relevant to the proposed PPP they are indirectly relevant and for the sector as a whole. Issues included:

Staffing and education, was something raised by many stakeholders, with concerns over access to sufficient numbers of qualified staff and also of the pipeline of staff being trained. The main education and training for fusion is carried out by universities and research labs, with EUROfusion members playing a key role. One of the issues was a lack of work for those in both industry and research as projects come to an end, for industry particularly for ITER, for research particularly as PhDs come to an end. Further efforts on education and training would help. At the same time the PPP is intended to provide a demand for qualified staff to keep people in the sector by providing new project opportunities and career pathways.

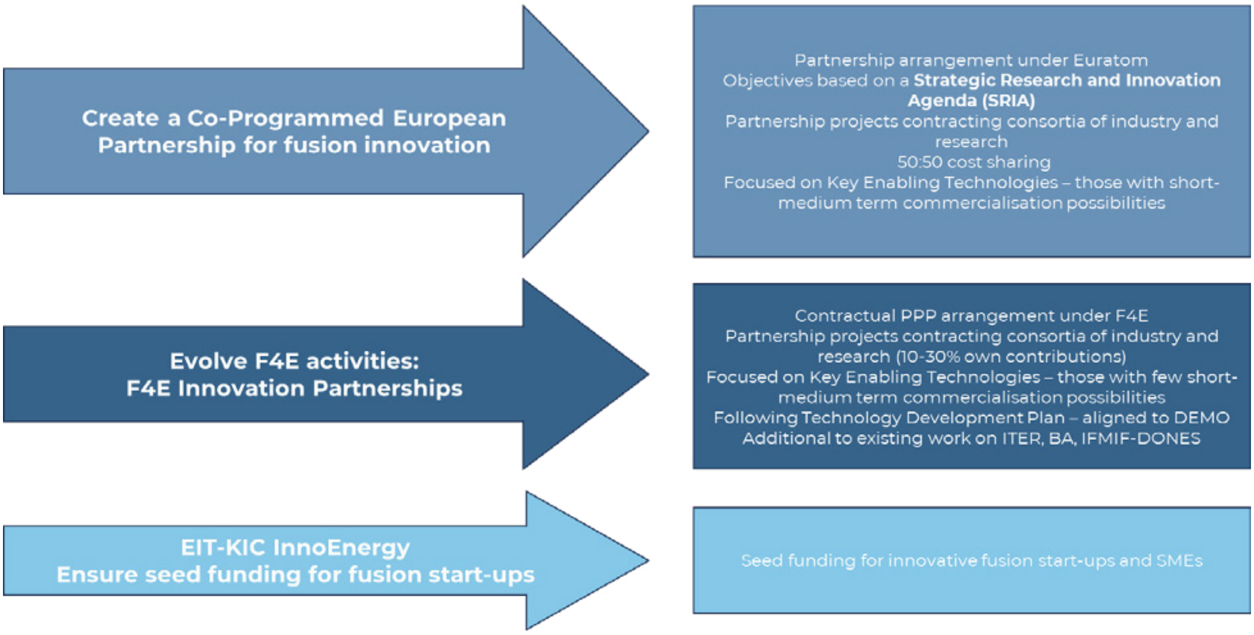
An **EU-wide regulatory framework** is an additional crucial aspect to consider for the success of fusion energy development, which should be developed by the European Commission. Developments in the UK and US, which have both separated fusion from fission regulation, could pave the way for more streamlined and efficient regulation specific to fusion technologies. The involvement of organizations like the International Atomic Energy Agency (IAEA) in setting standards and guidelines for fusion will be essential to ensure safety and international cooperation. Supporting Member States to speed up their consideration and reform of nuclear regulation to accommodate fusion, whilst also bringing consistency across MS will be important.

Licensing rules can also have a significant cost impact on fusion projects. Clear and efficient licensing processes will be vital to facilitate the development and deployment of fusion technologies. If fusion can e.g. be *classified as carbon-neutral or renewable energy*, it could attract more interest and investment from private companies and other stakeholders.

5 CONCLUSIONS AND RECOMMENDATIONS

Based on the analysis of the fusion funding landscape, the needs of different stakeholders, the main options available and the urgency for action we propose the following approach to funding fusion innovation in the EU.

Which instruments do we recommend



Evolve the focus of F4E funding to key enabling technologies: the existing procurement and work associated with ITER (and to a lesser extent Broader Approach) remains crucial to the role of F4E but as both move towards completion and operation the involvement of the industrial supply chain diminishes. The focus of F4E should also evolve towards its other objectives, namely towards DEMO and with this an increased focus on industrial innovation. Procurement of products and services from industry will continue to have a role in DEMO-related activities but not at a scale to address the emerging gap in support to industry innovation. However, there is also scope for an evolution in F4E activities, underpinned by its industrial policy. **We recommend that as soon as practical F4E starts a programme using the Innovation Partnership instrument to support industrial innovation in key enabling technologies**. We recommend the following characteristics apply to this F4E mechanism:

- It would reprioritise available F4E budgets, e.g. unspent from ITER, to use these towards F4E mandated objectives towards DEMO.
- Such a programme would target key enabling technologies of direct future relevance to DEMO – as determined in the F4E technology development plan (TDP), which should also align with the SRIA of the CPEP.
- The scope can be restricted to magnetic confinement approaches, but we would recommend that in addition to tokamak approaches, that technologies relevant for stellarators are also considered.
- The targeted technologies should primarily be those that do not have clear short-medium term (i.e. within 5-8 years) commercial possibilities or applications outside the fusion sector. Examples include: Tritium fuel cycle, heat exhaust systems.

- The possibility to move quickly is important for two key reasons: (1) to show quick wins of the new approach to EU fusion innovation funding; and, (2) as a pilot demonstration of the type of projects that may also be funded under the CPEP.
- Starting with a handful of pilot projects will also enable F4E to organise itself to effectively and efficiently select and administer such programmes, this may require a learning process compared to existing ITER procurement.
- To ensure a partnership approach some conditions need to be attached to the funding, including the necessity of at least one research partner in an innovation partnership; and the necessity of a contribution (in-kind or financial) to the overall cost to be made by the industry and research partners, i.e. it is not a grant/procurement contract.
- Given the focus on technologies further from market and/or with fewer applications outside fusion the expected contribution from industry is recommended to be in the range of only 10%-30% of total costs.
- An EC endorsement of this instrument and use of funds by F4E would reinforce the existing mandate that F4E has (towards DEMO and industrial innovation) and allow it to move forward with confidence.

Create a Co-Programmed European Partnership for fusion innovation under the Euratom framework to begin as soon as practical, ideally during the 2025-2027 work programme, but at least from the next MFF period in 2028. This would complement the F4E innovation partnership approach, but be distinct with the following characteristics:

- It should target a budget of tens of millions each year e.g EUR 30-100 million, potentially smaller budgets could be envisaged in the first years as the programme starts up. Larger budgets would very likely be necessary in future to cover the cost of large-scale technology development and demonstration.
- The Strategic Research and Innovation Agenda (SRIA) should target key enabling technologies overall, but with a focus on those with clearer short-medium term (i.e. within 5-8 years) commercial possibilities or applications outside the fusion sector. The rationale for this is based on the necessity of these commercial possibilities to attract industry and the necessary 50% matching contributions, and also for coherence with the proposed F4E instrument. Examples for focus include: Superconducting magnet manufacturing technologies, heating systems (gyrotrons, neutral beam injectors), remote handling systems.
- We recommend a split of around 75:25 in funding, with 75% reserved for key enabling technologies which are DEMO relevant, and 25% reserved for other fusion approaches, allowing for investment in technologies relevant for inertial fusion, magneto-inertial fusion or other magnetic confinement approaches. Reserving this smaller element provides a route for EU-firms with high-risk/high-potential approaches to scale.
- Activities for the main (75%) segment should be focused on development and demonstration projects. For the other approaches (25%) segment a broader variety of research activities could be foreseen, including for example, funding of INFUSE style innovation vouchers for firms to purchase time/expertise/knowledge from EU research institutions.
- The DEMO relevant part should also help to position the EU industry in global supply chains for all magnetic confinement based fusion approaches, i.e. so that EU industry can also be a leading supplier for public or private fusion devices in the US, UK, China, Japan or elsewhere.
- It would be the expectation that consortia bidding on the calls launched under this fusion PPP are led by industry, but include research partners. Start-ups could also be foreseen as consortia leads, not only for the alternative approaches segment of funding, but also in the mainstream magnetic confinement segment.
- CPEPs are typically required to be time-limited, aligning with the multi-annual financial framework periods. However, the need for a fusion PPP could extend all the way through to the construction and operation of a demonstration fusion power plant, i.e. possibly into the 2040's and 2050's. This should already be kept in mind when setting it up, particularly in the design of the Strategic Research and Innovation Agenda.
- Specifics on CPEP governance, process, IP rules are addressed separately.

Ensure a minimum of funding availability for fusion in the EIT-KIC InnoEnergy: the primary focus of this is to ensure there is a level of seed funding for fusion start-ups in the EU, this should include not only companies pursuing their own fusion approaches, but also SME's in the supply chain.

In future other instruments may also become relevant: the Innovation Fund, Breakthrough Energy Catalyst, EIB and other funds can all become more interesting in future as the TRL for fusion and the key enabling technologies increases. In the context of DEMO it may also become interesting to explore the creation of a specific company or partnership under Euratom to finance the construction, this is unlikely to be relevant before 2030.

Note: it is important to mention that the proposed PPP approach is developed on the basis that it has no impact on the ongoing work of EUROfusion nor on F4E work on ITER, BA, IFMIF-DONES, i.e. any PPP would be additional. Therefore the existing work carried out via EUROfusion should continue unchanged, this includes the scientific work at the lowest TRLs for key enabling technologies, and the early conceptual and design work for DEMO. The primary target group of EUROfusion funding is the research community, but industry also has a small involvement, as a supplier, for example through framework contracts to support the DEMO concept and design work. The funding from EUROfusion is also crucial to continue to develop and train a pipeline of staff for the sector as a whole.

What would these changes mean for key stakeholders in the fusion ecosystem?

- **Industry – supply chain:** at present the supply chain has an expectation for only relatively small short-medium term opportunities from public fusion funding in the EU, primarily in the last ITER-linked procurement, other projects such as IFMIF-DONES and DTT, and then early design work for DEMO. Beyond this, major work is not foreseen for 10 years or more, when more serious work on DEMO may begin. The F4E and CPEP instruments would provide a significant expansion and boost in opportunities for the supply chain in the short-medium term to work on fusion projects to boost innovation, competitiveness and staff retention. The mix of instruments accommodates the differing needs and capabilities of the supply chain (large-small, tier 1-tier 2) to invest in innovation for fusion, by allowing for varied levels of contributions.
- **Start-ups:** at present there is almost no funding at EU level for start-ups. The new instruments provide a mechanism to encourage further start-ups (seed funding through the EIT-KIC), and also for existing start-ups to progress and scale up through the CPEP. For more mainstream start-ups in magnetic confinement approaches (e.g. Gauss Fusion, Renaissance Fusion, Proxima Fusion) these could be fore-seen to lead consortia researching into key enabling technologies relevant for their own approach, but also for DEMO and more broadly – they could potentially also be foreseen to become involved in F4E Innovation Partnerships. For other start-ups there would also be possibilities through the CPEP under the alternative approaches (25%) allocation to also research into relevant technologies and try to avoid the situation, for example with Marvel Fusion, where investment is attracted outside the EU.
- **Research labs:** the new instruments would provide new avenues for funding and technology transfer from the research sector. This would fund more research work by these institutions, improve career pathways for research staff and make working in the sector more attractive. Being involved in the new instruments would also help to ensure that scientific knowledge is also gained.
- **EUROfusion:** in addition to continuing to drive scientific research and education in the EU, and the initial concept and design work for DEMO the new initiatives would also provide opportunities for EUROfusion. Particularly for the CPEP instrument EUROfusion would be likely to be highly involved in the setting of objectives and the SRIA, and the alignment of both the F4E Innovation Partnerships and CPEP on magnetic confinement and DEMO would boost progress in these areas.
- **F4E:** the recommendation for the Innovation Partnership instrument would provide F4E with a short-mid term goal which makes full use of the industrial network and technical capabilities developed as part of ITER, and also uses available budget which may otherwise be lost. Whilst it would not be expected to be a direct member of the CPEP it could play an important role in its formation (particularly the ILO

network would be important) and in its administration, potentially supporting the EC in evaluating calls. In addition it would continue to play its crucial role in funding ITER, and potentially grow its role further in DEMO, discussing responsibilities with EUROfusion.

What would this mean for DEMO?

- **Continue work of EUROfusion and F4E:** The conceptual and design work that can be carried out in the short-medium term would continue to be addressed through EUROfusion and F4E procurement channels.
- **New instruments support necessary technology development:** In addition, the work through both the F4E Innovation Partnership and CPEP instrument would ensure work starts on the key enabling technologies that are still needed for DEMO, using utilise industry expertise to accelerate progress.
- **Longer term next steps can be taken:** In the longer term, i.e. in around 10 years, the work under these partnerships, will have paved the way for more detailed design work for DEMO. The involvement of EUROfusion in the CPEP should help to ensure that the necessary integration is feasible. This could potentially be addressed through a new Euratom-specific partnership, i.e. a company setup for the purpose of constructing DEMO. We assess such an arrangement for DEMO to be premature at this point in time, therefore the DEMO-aligned KET focus is recommended to ensure relevant innovation is funded.

What steps need to be taken by the EC?

There are a few key steps that need to be taken, and a role for the EC in each of them:

Establishing the policy backing for a Fusion CPEP. We understand that if a decision to go-ahead is made, that it would be created under Euratom auspices and therefore would not need to go through the current Horizon Europe candidate partnership selection process. However, the necessary arrangements by EC services will still need to be made to ensure that a CPEP (under Euratom) could begin as soon as possible within the next few years.

Communicate with industry and support the establishment of an EU representative organisation for the CPEP. The EC should speak with industry and make clear that the industry needs to organise itself in a way that is consistent with a CPEP. **A Coordination and Support Action** (CSA) could be used to support industry and the research community in a process to establish such an organisation. However, this may slow down the process and a faster alternative without support could be promoted with stakeholders. This should utilise both the Fusion Industry Innovation Forum (FIIF) and Fusion Industry Association (FIA), and should also make use of F4E and their Industrial Liaison Officer networks, with also EUROfusion involved. The EC does not need to be directly involved in the formation of an EU fusion industry trade association (distinct from the organisation to run the CPEP) as part of this process, but it could be a welcome additional outcome.

Propose a Strategic Research and Innovation Agenda (SRIA) and work with stakeholders to finalise it. Taking a step towards an EU fusion innovation strategy (see below), the EU should propose a SRIA which defines the main areas of focus and milestones to be achieved and also emphasises how the CPEP should contribute to accelerating fusion innovation and supporting industry. It also needs to be consistent and coherent with the other instruments and ongoing activities. Following the process outlined in 4.3.1 the SRIA should be discussed and refined with the industry and research stakeholders of the CPEP to further detail and refine towards a final agreed SRIA, this could be as part of the CSA noted above.

Give policy backing for F4E Innovation Partnerships. Whilst F4E already has a mandate for work towards DEMO, there could be sensitivities on reprioritisation of F4E budgets towards DEMO-oriented activities, particularly in the context of ITER delays. Receiving EC backing to take this route would bolster F4E to take action. The EC should review the F4E Technology Development Plan (TDP) to ensure consistency and coherence across the proposed PPP instruments.

Establish a route for start-ups to access seed funding in EIT-KIC InnoEnergy. As part of EIT-KIC InnoEnergy or a similar mechanism the EC should verify and, if possible, ensure that sufficient funding is available to invest in fusion start-ups in the EU. Start-ups would also be eligible to participate in the proposed CPEP and F4E instruments.

Develop an EU innovation strategy for fusion. An over-arching EU fusion vision or strategy was a clear request from stakeholders throughout the work. Whilst a full strategy may not be feasible at this point, at least a fusion innovation strategy is needed which defines and ties together which innovation objectives should be achieved, how and which instruments should be used for each. This should also take into account national programmes. An EU innovation strategy for fusion will help to set a positive and coherent landscape for fusion innovation across the EU and also define the role of the main stakeholders and each of the instruments to be used.

Which specific recommendations are made for the CPEP?

In addition to the overarching recommendations on instruments set out at the start of this section we recommend for the CPEP the following:

Setting the SRIA

- The Strategic Research and Innovation Agenda should guide the CPEP, defining priorities and funding needs, and emphasizing collaboration among all stakeholders.
- The SRIA should be crafted with clear representation principles, ensuring balance, geographic diversity, and alignment with existing strategic roadmaps (that of EUROfusion and F4E) as well as technological priorities, focusing on KETs for magnetic confinement fusion (DEMO-aligned) as well as high-risk but high-reward other fusion approaches.

Governance

- An Executive Board with a 4:3 or 5:2 industry-research ratio, and a Secretary General managing day-to-day operations.
- Membership, should be broad but on a paid basis with annual fees to support a secretariat, and which aims for smooth cooperation and communication.
- Roles should be clearly defined, with a decision to be taken by the EC on the role for F4E, if any, in the award and selection process.

Contributions, ownership and activities

- Intellectual Property (IP) management is critical, favoring industry in early stages and evolving as maturity and funding increase.
- Calls and activities should follow a milestone-based approach, fostering innovation while tracking meaningful progress.

Monitoring and evaluation

- Coherence with other partnerships is vital for the CPEP, fostering strategic collaborations with leading candidates active in relevant fields (such as high-Performance Computing, AI, and Made in Europe initiatives is recommended.
- Robust KPI monitoring and reporting, following Horizon Europe guidelines, will help track the CPEP progress as well as the partnerships' functionality and investments. Impact case studies can be used to highlight lessons learned.

- A Monitoring Group should be set up, involving public and private stakeholders, ensuring effective risk management and aligning with existing models.
- The establishment of a structured risk management system is recommended, involving both public and private stakeholders, to mitigate risks financial encountered during the partnership.

Other recommendations

In addition the following issues were raised during the project and lead to recommendations:

- An advice should be given by the EC on whether EUROfusion should become a legal entity. In the context of a PPP this can be an advantage for the research community.
- Speed is crucial – both in taking a decision on which actions to take, but also in the processes to create and operate the instruments. The US Milestone program provides a benchmark for this, from announcement of the program in Sep 2022, first calls were launched in Dec 2022 and first awards made in June 2023, a total of around 10 months. Similar speed should be an aim of EU action as the US (and UK) have a head-start in fusion PPP schemes.
- Regulation: whilst nuclear regulation is a Member State responsibility greater clarity is also a frequent request of both industry and start-ups. It is recommended that the EC examine what could be done to speed up regulatory discussions and reform by key Member States with the aim of risk-proportional regulation for fusion, and consistency across MS.

ANNEX A: INTERVIEW GUIDE TEMPLATE

Date & Time: xxx
Interviewee: xxx
Interviewers: xxx

Introduction

Background

Trinomics are carrying out a study on behalf of the European Commission Directorate-General for Energy to assess ways in which innovation and investment in fusion energy by European industry could be fostered through a public-private partnership (PPP) approach. This will inform EC decision making in the field of fusion energy and the possible development of such a PPP approach.

The study aims to identify and analyse PPP schemes in Europe, and globally, and both within fusion energy and in other relevant areas of innovation. In doing so it seeks to identify the most important characteristics of such schemes and how these might be best applied within a European PPP for fusion energy, taking into account the needs and barriers to participation by private and public organizations. The final outputs of the work will provide recommendations for an appropriate EU policy approach to a PPP in the field of fusion energy.

This interview intends to better understand your experience, needs and opinions relating to PPPs and fusion energy.

Anonymity option	Choice of the interviewee (Y/N)
With your permission, notes (including automatic transcription) and an audio recording will be made during the interview. The recording is only to support the notes. You can stop the recording at any time. The recording will be deleted within 3 weeks and the minutes of the interview will be shared with you for approval.	
Your views will be treated as anonymous and assigned to your organization only. Alternatively, your views can be assigned to a generic organization type (rather than your specific organisation). If we intend to quote your views, we will contact you first for your approval. Please express your preferred option.	
The final (and approved by you) version of the interview minutes will be shared with the project team.	

Definition

Public-private partnership

A public-private partnership (PPP) is any government funded programme that gets a publicly-funded organization to work with a private organization towards a joint goal – which could include research and innovation activities, or delivery of a project (e.g. infrastructure, power plant), product or service. This definition excludes programmes such as fee for service contracts, indefinite delivery contracts, public grants or other government funding programmes for the private sector. This is an important distinction because the public sector currently funds majority of fusion activities around the world, but a PPP is a specific category of these arrangements. In PPP arrangements the public authority typically makes payments (sometimes linked to milestones) to a private partner and/or grants them rights to the outputs/proceeds of the partnership. The private party is typically expected to contribute also its own financial commitment and take on part of the risk and management responsibilities.

Interview questions

Introduction

1. Can you please provide a short background on your organization, its specialisations and its goals?
2. Can you highlight any public-private cooperation you already engage in?

Fusion involvement, interest and lessons

3. Have you been involved in supply of products or services to ITER/Broader Approach, or other fusion-relevant initiatives public or private? If yes, which, and…
   (1) What were the key aspects of this?
   (2) How did you experience the cooperation with F4E or your other contracting partner?
   (3) To what extent has the experience, knowledge and technology development of your involvement helped your organisation generally? And in the field of fusion? Have you been able to re-use the knowledge and technology?
   (4) Have there been any barriers, i.e. restrictions on IP or technology transfer, to utilizing what you gained in this participation?
   (5) Are there changes in contracting and public-private cooperation you would recommend?
4. Are you interested to participate in the future DEMO programme in Europe, and/or in supplying other fusion initiatives? If yes, which, and…
   (1) Which component would you like to develop or deliver for fusion?
   (2) Would you recommend a PPP approach for such a programme?

PPPs

5. Is there a need for an EU PPP programme for fusion energy?
6. In your opinion what should be the main objectives of an EU PPP programme for fusion? *E.g. enhancing cooperation between stakeholders, accelerating EU fusion start-ups, building an EU fusion ecosystem, engaging industry to invest, bringing the private expertise to move from reactor to energy plant, …*
7. What is your opinion on these key characteristics of a potential EU fusion PPP? And what are the main needs, for your organisation to participate in a potential EU fusion PPP?
   (1) Risk sharing – how should this be shared between public and private organisations?
   (2) Funding and financial commitments - how should this be shared between public and private organisations?
   (3) Intellectual property and technology transfer – which commitments and rules on how this is shared?
   (4) Technology focus – is this needed? How focused e.g. MCF only? Component specific?
   (5) Types of projects that should be supported e.g. demonstration, and device/component design and development, research exchange, shared experimental time, training and education, etc.
   (6) Governance
   (7) Responsibilities and roles of participants
   (8) Award processes
8. What are the main potential barriers for your organization to participate in a PPP? for example
   (1) Intellectual property rules
   (2) Available funding
   (3) Complexity of process
   (4) Duration of process

(5) Lack of interest
(6) Low trust on reciprocity
(7) Lack of transparency and accountability
(8) Lack of professionals qualified to handle PPP projects

9. In which ways would you propose these barriers to be addressed?
10. Do you have experience with other PPP models that you would recommend to use in the EU for fusion? *If so, please elaborate on which and why*
11. What is your view on milestone-based programmes?
12. Do you think there is a useful role for international collaboration in fusion PPPs, i.e. EU-UK, EU-US, EU-JP?
13. Are there alternatives to a PPP that would better address your organisations needs?
14. Interest to participate in a workshop?

ANNEX B: STAKEHOLDER WORKSHOP AGENDA

9.30 – 10.00	Doors open and registration
10.00 – 10.15	Introduction and context to the project from the Commission's perspective (DG ENER) • Give the rationale and scope of a PPP study • Introduce the new coming EU Fusion policy developments
10.15 – 10.30	Introduction of the study, objective, methodology and global approach (Trinomics)
10.30 – 10.45	Lessons learned from the past and expectations for the future: (Trinomics)
10.45 – 12.15	Lessons from existing PPPs, with a focus on innovative funding and successful collaboration between research & industry (10' each) • Intro (Trinomics) • EU PPP co-programmed (BEPA) • EIT-KIC InnoEnergy (Novatron Fusion) • US PPP INFUSE (Commonwealth Fusion Systems) • US PPP ARPA-E (Realta Fusion) Main findings and global experience with various PPP, what lessons to extract (15') (Trinomics) Questions and answers (15')
12.15 – 14.00	Buffet - Lunch
14.00 – 14.30	Preliminary results of the study – from the interviews & research (Trinomics) • Key parameters for the design of a PPP for Fusion • Emphasising the importance of the industry and its willingness to participate in such PPP • Addressing IP, governance, funding, target, risk sharing, collaborative frameworks, etc.
14.30 – 15.30	PANEL - open to (EU) industry & research expectations and barriers, reacting on the preliminary results • What are the key aspects for the elaboration of a PPP in Fusion? Adding or amending the proposal made earlier • How to manage IP rights in the frame of a PPP, given the many synergies and different technology routes in fusion? • How can the design of the PPP Fusion find the most appropriate risk sharing balance between public & private? Proposed panelists • Dr Anika Stein (independent inertial fusion and industry specialist) • ASG superconductors • Assystem • EUROfusion • ENI

15.30 – 16:00	Q&A
16:00 – 16.15	Wrap up + Workshop conclusions and next steps (Trinomics) Closing words (EC)

ANNEX C: PROFILE OF PPP SCHEMES INVESTIGATED

The project team compiled a mapping of PPP models with the aim of providing a comprehensive sample of existing relevant schemes, across the EU and globally. A number of (non-fusion) programmes at EU level, funded under the Horizon Europe Partnerships 2021-2024, were selected for their differing structures, whole value chain coverage and for their technological component. Programmes in the US and the UK were also selected. Below is the list of PPPs identified as part of this task. The file includes the complete list of partnership programmes and their description.

To access the file referenced in this annex, please visit https://data.europa.eu/data/datasets/annex-c-profile-of-ppp-schemes-investigated?locale=en to download it from the online version.

ANNEX D: FUSION INVESTOR NEEDS: ADDITIONAL DETAILS

Angel investors

Angel investors are typically individuals with high net worth who invest in early-stage startups. They may be attracted to investing in fusion energy because of the potential for high returns on their investment, as well as the opportunity to contribute to the development of clean energy solutions. Angel investors may invest anywhere from a few thousand euros to a few million euros, with an investment period of several years. They may also be looking for the potential for an exit, such as through an initial public offering (IPO) or acquisition by a larger company.

Venture capital

Venture capital firms are investment companies that specialize in funding startups with high growth potential. They may be attracted to investing in fusion energy because of the potential for significant returns on their investment, as well as the opportunity to support the development of new technologies. Venture capital firms may invest several million dollars in a fusion energy startup, with an investment period of several years. They may also be looking for an exit, such as through an IPO or acquisition.

Strategic corporate and institutional investors

Strategic corporate investors are companies that invest in other companies that are aligned with their business objectives. They may be attracted to investing in fusion energy because of the potential for developing new technologies or expanding their operations in the clean energy sector. Strategic corporate investors may invest several million to several hundred million dollars in a fusion energy startup, with an investment period of several years to a decade or more. They may also be looking to acquire the company outright or form a strategic partnership.

Sovereign wealth funds

Sovereign wealth funds are investment funds that are owned and managed by governments. They may be attracted to investing in fusion energy because of the potential to support the development of clean energy solutions and to generate returns for their respective countries. Sovereign wealth funds may invest several tens or hundred millions to several billion euros in a fusion energy startup, with an investment period of several years to a decade or more. They may also be looking to acquire the company outright or to support the growth of the company over the long term.

ANNEX E: KEY ENABLING TECHNOLOGIES – A US PERSPECTIVE

Enabling Technologies (S. Woodruff, A. Stein)
Enabling Technologies
S. Woodruff, A. Stein

In order for a fusion system to become viable, reliable, and commercializable, ongoing investment in enabling technologies will be necessary. These enabling technologies span across various industries, involving research, development (R&D), and the creation of new products to support the realization of a fusion power plant (FPP). The U.S. Department of Energy's (DOE) Fusion Energy Sciences Advisory Committee (FESAC) has defined the term "transformative enabling capabilities" (TEC) in its 2018 report, titled "Transformative Enabling Capabilities for Efficient Advance Toward Fusion Energy" [1]. According to the report, TECs refer to revolutionary ideas that are crucial for fusion power or have the potential to significantly accelerate progress towards the viability of an FPP. These TECs are categorized based on risk/reward, existing support, and degree of necessity.

While research into enabling technologies has traditionally been carried out through public programs hosted by government agencies and universities, the private sector has increasingly played an active role in their development. This shift is attributed to growing confidence in plasma physics and fusion sciences, as well as the emergence of enabling technologies that reduce the costs associated with fusion R&D. Many private companies sustain profitability by developing technologies that can be utilized by other industries until fusion energy becomes a reality. Aerospace, medicine, manufacturing, data science, and other sectors are among those that overlap with certain fusion technologies.

The majority of research efforts thus far, as outlined in the 2021 prepublication "Bringing Fusion to the U.S. Grid" by the National Academies of Sciences, Engineering, and Medicine (NASEM), have focused on plasma physics and confinement. Specifically, emphasis has been placed on studying the plasma itself, the divertor, the first wall, magnets, and the heating system [4]. Ongoing research in these areas is crucial for attaining the required technology readiness level (TRL) for an FPP.

The TRL scale, ranging from 1 to 9, is employed by FESAC to gauge the readiness of various TECs in its 2018 report. The 2016 Technology Readiness Assessment Guide [3] is referenced to define each level in relation to an FPP.

TRL 1: Pure research
TRL 2: Applied research
TRL 3: Laboratory testing of individual components
TRL 4: Laboratory testing of integrated components
TRL 5: Field testing of integrated components
TRL 6: Field testing of scale prototype
TRL 7: Full-scale testing of prototype in cold conditions
TRL 8: System completed and qualified through test and demonstration
TRL 9: Actual system operations in full range of conditions
Table 3-1, "Technology Readiness Level Scale for Fusion" [1, pp. 3-4, Appendix C]

The FESAC report highlights the readiness levels of different individual technologies evaluated, with the majority falling between TRL 1 and TRL 3. The report identifies challenges, potential expectations, ongoing advances, and the role of existing technologies in further development [1]. A TRL 9 would indicate the operational status of an FPP.

FESAC's 2020 publication, "Powering the Future Fusion & Plasmas" [5], presents a comprehensive summary of past and ongoing fusion programs, along with a list of suggested areas for prioritized industry development in the United States. The report suggests that fusion R&D should focus on advancing technology for confining and sustaining burning plasma, withstanding extreme environmental conditions, and harnessing fusion power for electricity generation. Additionally, investments should target industries that facilitate timely and cost-effective design, engineering, and construction of the FPP.

The development of future enabling technologies in the fusion energy sector encompasses several key industries. These industries include fusion sciences, plasma sciences, material sciences, magnet sciences, laser sciences, data science, network collaboration, advanced manufacturing, and advanced sensors and control systems. When considering the entire spectrum of fusion energy development, the enabling technology space can be categorized as follows:

- Advanced Manufacturing
- Materials Science
- Data Science
- Advanced Sensors, Instrumentation, & Control Systems
- Tritium Fuel Cycle
- Blankets
- Magnets and Superconductors
- Lasers and Optical Technology
- Networking & Collaboration
- Other Supporting Technologies

In the subsequent sections, each of these categories will be discussed in detail.

Advanced Manufacturing

To ensure the efficient construction and maintenance of a fusion power plant (FPP), the implementation of Advanced Methods for Manufacturing (AMM) will be crucial. The Nuclear Energy Enabling Technologies (NEET) program, under the DOE Office of Nuclear Energy, emphasizes that AMM should focus on simplifying, standardizing, and reducing labor in manufacturing, fabrication, assembly, and construction processes. The goal is to achieve reliable and high-strength plant assemblies. Several technologies contribute to these efforts, including additive manufacturing (AM), modular fabrication, data configuration management, welding and joining technologies, as well as surface modification and cladding processes [6].

In the context of welding and fabrication technologies, the NEET program highlights the importance of electron beam and laser welding for joining heavy reactor components. To enhance the speed and quality of welds both inside and outside the shop, NEET recommends real-time or near real-time welding feedback. Additionally, surface and subsurface flaws often arise from the formation of alloys at joining interfaces during cladding and surface modifications. Advances in bonding processes such as solid state, cold spray, or other techniques can help eliminate these flaws [6]. Multidimensional data visualization, organization, and analysis tools play a crucial role in the complex design and maintenance of power plant civil engineering and mechanical designs. These innovations also support ongoing R&D efforts related to other enabling technologies.

AM, which relies on computer-aided design (CAD) models and technologies such as lasers, electron beams, friction stir welding, or conventional methods, enables the fusion of thin layers of solid or powder material into a two-dimensional pattern, ultimately creating a near-net shape of the original model [6]. Unlike traditional removal methods like machining and etching, AM adds materials to build structures from a bottom-up approach. This approach allows for maximum customization in fabricating individual parts. Advancements in AM technology facilitate the affordable and timely construction of pilot plant designs and reactor components with complex geometries and transitional structures. These components often require refractory metals that are challenging to machine and demand precise control of material microstructure—capabilities that are being advanced through current AM research [1]. Moreover, core reactor research involves iterative design-build-test cycles with experimental changes to materials and structures. AM accelerates early-stage R&D to a readiness level that can be quickly and cost-effectively adopted by the fusion industry, while minimizing waste. However, as noted in FESAC's 2018 report, AM must undergo testing specifically for fusion applications. Furthermore, additional studies are needed to determine how AM-processed components are affected by the extreme environmental conditions present in a fusion reactor, including neutron irradiation, corrosion, erosion, plasma particle flux, and high heat flux. Continuous research and investment are rapidly advancing technologies that enable mixed material printing, multi-scale features, and the production of larger part sizes [1]. To fully harness AM capabilities, the fusion industry must leverage existing R&D alongside fusion-specific research, including studies that enable the use of fusion materials in AM processes.

Examples of organizations investigating advanced manufacturing technologies for fusion include:

REM Surface Engineering has been engaged in an innovative project that focuses on using additive manufacturing to improve the surface finishing of Radio Frequency (RF) components for fusion reactor applications. This venture aims to address and rectify identified issues in current reactor environments, ultimately boosting the lifespan of the components and systems.

Radiabeam Technologies, LLC has been actively exploring the utilization of high-temperature electron beam additive manufacturing to improve tungsten plasma-facing components in fusion reactors. The key goal of the project is to decrease the cost of fusion energy reactors by merging complex tungsten assemblies into one single unit with improved performance characteristics.

Transition45 Technologies, Inc. has been dedicating their research efforts to the development of novel additively manufactured coatings for enhancing plasma performance. This work covers a wide range of applications, from the creation of nuclear degradation-resistant materials to the development of corrosion-resistant medical devices, aiming to accelerate economic growth and tackle societal challenges.

KIT is a hub for advanced manufacturing techniques, focusing on the engineering design of ITER fusion reactor components. Concurrently, they are driving the development of strategically crucial technologies for ITER. Key areas of this advancement include material development for high-stress components like the blanket and the divertor, and the incorporation of high-temperature superconductor technologies for fusion magnets.

Materials Science

Material science plays a crucial and interconnected role in the development of fusion components, closely tied to other enabling and core technologies. The majority of reactor components, including plasma-facing parts, process control equipment, blanket components, and structural materials, must possess the ability to withstand a range of demanding conditions. These conditions include high temperatures, high heat flux, plasma particle flux, neutron irradiation, corrosion, neutron loading, mechanical loading, erosion, redeposition, and the impact of hydrogen and helium particles. Changes in material surface properties can significantly affect the intended functions of individual components, fuel recycling, and impurity emissions. In-depth experimental studies at the coupon level (centimeter scale) are necessary to enhance our understanding of material properties [1].

The current technology readiness level (TRL) for fusion materials remains quite low. Conventional materials are inadequate for handling the extreme conditions found in fusion reactors. The development of new materials will play a pivotal role in determining the feasibility of a commercially viable fusion energy system. Research and development efforts will need to investigate the long-term durability of these new materials. It is worth noting that the typical development timeline for new materials in the automotive industry exceeds 20 years, according to the Materials Genome Initiative. “Powering the Future: Fusion Plasmas” highlights the lack of facilities capable of generating the necessary damage and transmutation rates to study material exposure to neutron fluxes, which represents a critical gap in international fusion science studies [5]. Currently, fission research and development serve as the primary means for developing irradiation-resistant materials, but these materials do not possess the required spectrum for fusion conditions.

Several promising solutions for high-temperature tolerance have emerged, including ultra-high-temperature composites (UHTC), MAX phases (layered ternary carbides and nitrides), high-entropy alloys (HEA), continuous fiber composites, laminate composites, and non-tungsten composites. Refractory-based materials with complex composite geometries, such as ductile phase-toughened tungsten composites, also demonstrate potential.

Developing materials with the necessary characteristics for each component entails accommodating varying environmental extremes in material structure and composition. While computer simulations can aid in this development process, challenges arise in collecting the required input data. Such models necessitate a time scale spanning 20 orders of magnitude and a length scale spanning 8 orders of magnitude. In light of this, FESAC has recommended the establishment of predictive material discovery simulations to efficiently scan and validate new materials [1].

Examples of companies undertaking materials science projects for fusion include:

SiLi-ion Inc. has recently been working on a Small Business Innovation Research (SBIR) project that involves low-temperature plasma synthesis to create next-generation battery materials. This research aims to produce superior battery materials that exceed the quality of those currently available commercially, and position SiLi-ion as a leader in the battery industry.

Shear Form, Inc. is conducting research to develop a functionally graded composite plate that can endure the extreme environments in ITER fusion reactor divertors. The project’s main objective is to create a composite of tungsten and copper that can withstand intense plasma while safely conducting heat away.

Air Squared, Inc. is in the process of investigating plating alternatives for Aluminum Tritium Scroll Vacuum Pumps to enhance durability and decrease production costs. They aim to evaluate the potential of easily machined aluminum plated with nickel or other elements to replace stainless-steel tritium containment.

Alemnis is at the forefront of advanced material testing for fusion reactor components. Fusion reactors demand robust materials selection due to their challenging operational conditions. A significant component under continuous improvement is the viewing port, which includes fused silica, an Inconel ferrule, and an aluminium bonding layer consolidated via diffusion bonding. The precise design parameters of such assemblies often rely on three-dimensional finite element models (FEM). However, FEM simulations need accurate stress-strain curves, especially challenging to obtain for complex systems with dissimilar joints. Alemnis addresses this issue using dynamic spherical nanoindentation to chart the stress-strain properties across diffusion bonded joints. This approach, combined with an automated post-processing protocol, provides crucial data like yield stress, strain parameters, and elastic moduli, assisting in optimizing fusion reactor component design.

The Max Planck Institut für Eisenforschung GmbH is researching advanced materials for fusion energy applications. Their focus is on materials such as AISI 431, examining how deep cryogenic treatment (DCT) can modify its properties. The study aims to understand the effects of DCT on the material’s microstructure and its impact on corrosion resistance, providing insights for potential applications in fusion reactors.

Data Science

Within the broad field of data science, there are specific disciplines that hold significant potential for fusion research. Advanced algorithms, modeling and simulations, and high-performance computing (HPC) work collaboratively to enhance our understanding, control, and optimization of fusion system behaviors, including plasma confinement, turbulence, and transport [1].

Prominent areas within advanced algorithms include machine learning (ML) and artificial intelligence (AI), which have proven critical in the magnetic fusion sciences. These disciplines are empowered by advancements in HPC and, in turn, contribute to further progress in HPC itself [7]. ML and AI, when combined, can expedite scientific discoveries by overcoming limitations in knowledge regarding underlying processes and extracting insights from vast datasets. Their applications span algorithmic design of fusion concepts, discovery of fusion power plant (FPP) materials, technology readiness level (TRL) assessments, and real-time or Faster-than-Real-Time simulations, diagnostics, and control system optimization for the FPP [1]. Concurrent research and development efforts in HPC and exascale computing are crucial for many of these advancements. FESAC recommends funding projects that specifically develop algorithms for the fusion energy sciences. Additionally, advances in HPC computing are essential for the realization of real-time GPU and real-time many-CPU clusters, with new-generation HPCs currently being developed through U.S. DOE projects [1].

Modeling, simulation, and visualization technology play a supportive role in the journey towards fusion energy commercialization. Driven by advancements in HPC and the broader field of data science, multiscale/multiphysics modeling and simulation tools enable fusion energy scientists to utilize the underlying physical characteristics of fusion reactors, unlocking insights that traditional empirical models cannot provide. Empirical models are limited by the vast amount of data required and are contingent on the specific conditions and systems from which the data was collected [8]. To effectively deploy and operate a commercial fusion system without excessive data collection, advancements in modeling, simulation, and visualization are indispensable. These advancements must enable accurate prediction and handling of the complex interactions among plasma, materials, and engineering processes within a reactor. Developing simulation tools that possess these capabilities, alongside validated models to utilize them, is of utmost importance [5].

It is crucial to emphasize that foundational research across the fusion energy sciences must continue to receive strong support for data science advancements to be effectively utilized. FESAC's 2020 report highlights the importance of fundamental data, such as cross sections, rate coefficients, and materials properties, which serve as the backbone of modeling and algorithms. Often, limitations in models stem from insufficient input data rather than a lack of understanding in plasma physics. Therefore, research that generates and verifies fundamental data is vital for advancing plasma science, although clear sources of funding for such research are currently lacking [5].

Examples of companies investigating approaches using data science include:

Tech-X Corporation has been concentrating its efforts on developing a user-friendly cloud modeling software that can accurately predict the performance of plasma processing devices in the field of microelectronics.

Silver Fir Software, Inc. has been focusing on creating a product designed to streamline the numerical simulation of radiation fields in fusion energy devices. This tool aims to accelerate the development and the eventual adoption of fusion energy technologies.

HZDR is spearheading the ERC-funded PREXTREME project, focused on addressing the fermion sign problem inherent in quantum Monte Carlo calculations. This endeavor is essential to discern the phase transition behavior of hydrogen at high pressures, explore its electronic properties related to the development of large celestial bodies, and optimize hydrogen pellet compression for fusion reactor energy production.

The project's insights have the potential to bring transformative advancements to quantum many-body theory and could illuminate areas like high-temperature superconductivity.

Advanced Sensors, Instrumentation, & Control Systems

FESAC recognizes diagnostics, actuators, and controls as pivotal transformative capabilities for the field of fusion sciences. These technologies play a critical role in monitoring, controlling, and optimizing plasma behavior. Without reliable plasma feedback control, transient events—whether arising from reactor designs or external conditions—can result in the release of plasma energy, causing damage to plasma-facing components [1]. Reactor divertors, in particular, face significant challenges due to the occurrence of intense heat fluxes in the exhaust, which can cause substantial damage.

Efforts aimed at predicting, controlling, and mitigating these events will be closely intertwined with advancements in data sciences and plasma sciences. To effectively manage plasma instability in real-time, control systems will require lightning-fast algorithms. FESAC's 2018 report acknowledges that while routine operational control is unlikely to utilize supercomputing due to its high power demands, advancements in the technology will enable optimized control-level models and algorithms [1]. Such advancements will rely on data acquired from plasma research. Furthermore, progress in multiscale (MS) modeling will contribute to enhancing the durability of plasma-facing components, divertors, and diagnostic equipment, enabling them to withstand the demanding environmental conditions.

Research and development endeavors targeting sensor technology will significantly contribute to ongoing plasma research. Diagnostic equipment currently employed in the International Thermonuclear Experimental Reactor (ITER) includes magnetic sensors for measuring plasma and reactor structure currents. Neutron diagnostics at ITER encompass neutron cameras, spectrometers, and flux monitors. A comprehensive overview of modern neutron detection techniques was compiled by the International Atomic Energy Agency (IAEA) in 2020 [11]. Optical systems at ITER employ Thomson Scattering systems and interferometers to measure temperature and density profiles across the plasma. Bolometric systems utilize sparse-data tomography to gather information on spatial distribution and radiated power. Spectroscopic instruments and neutral particle analyzers provide insights into various plasma parameters, such as impurities, density, input particle flux, ion temperature, helium density, fuelling ratio, and plasma rotation. Additional sensors facilitate measurements related to plasma position, tritium conditions, erosion, residual gas, divertor conditions, and more. Furthermore, non-destructive methods employing various sensors can be utilized in reactor research to detect degradation of reactor components [10].

The practicality of sensors in collecting vital reactor data is clearly demonstrated by ITER. NEET's annual reports highlight advancements made in fusion sensors and instrumentation, with the most recent publication showcasing progress in measuring, controlling, and managing nuclear systems [13]. Future endeavors in this area will require close coordination among the fusion sciences, data science, and material science domains.

Organisations exploring new Advanced Sensors, Instrumentation, & Control Systems include:

NUSENICS, LLC has been exploring the development of advanced fiber-optic bolometers that can provide essential diagnostic information for the development and operation of fusion devices. The project seeks to outperform existing electronic bolometers in terms of sensitivity, size, cost, and durability.

Luna Innovations Incorporated has proposed the development of a novel fiber-optic based monitoring system for superconducting magnets. The aim is to improve coverage and response times, enabling stable and safe operation over longer periods, thereby making fusion power systems more viable.

Lupine Materials and Technology (LMT) has been working on the development of a distributed sensor that can simultaneously measure strain and temperature variations. The goal is to provide an unprecedented level of protection to High Temperature Superconductors (HTS), enabling the development of a new generation of fusion reactors.

3-Sci's introduction of the CCDS (coaxial cable distributed sensing) system provides a detailed monitoring solution. Using sensing sites located along a robust coaxial cable, the CCDS can capture continuous measurements across extended distances or substantial surface areas. This technology can accurately detect a range of parameters, including stress, strain, temperature, vibration, and pressure, highlighting its capability for diverse applications.

Ansaldo Nucleare - Control Systems for ITER Tokamak Assembly

Ansaldo Nucleare has undertaken the design of two machines for the ITER Tokamak assembly phase. These machines will transport the plugs, which house instrumentation, from the assembly hall to the Vacuum Vessel's designated ports. The Vacuum Vessel, a crucial component that contains fusion reactions and serves as a primary safety barrier, has multiple port levels. Ansaldo's machines are designed for operations at the equatorial (horizontal) and upper (inclined) ports. Remote handling tasks, essential for inspections or repairs of Tokamak components, hinge on these designs. After this design phase, Ansaldo Nucleare will transition to the manufacturing design stage, followed by the production of the machines.

Tritium Breeding Technologies

Deuterium (D), also known as heavy hydrogen, is abundant in the Earth's oceans. However, tritium (T), a crucial component for D-T fusion reactors, is rare and found in trace amounts within the Earth's atmosphere. The realization of a fusion power plant (FPP) depends on technologies that enable tritium production and facilitate a closed tritium fuel cycle. Extensive research is necessary to deepen our understanding of tritium handling and safety, environmental considerations, breeding technologies, and the complex interactions of tritium within the fusion reactor. The industry must investigate various aspects, including tritium burn fraction in the plasma, processing from plasma exhaust to fueling, blanket breeding, extraction in breeder and coolant streams, system losses, and more [4].

In DT reactors, tritium is produced in the reactor blanket through neutron-lithium nuclear transmutation reactions. Numerous blanket concepts have been developed, utilizing liquid metal or solid metal configurations. However, the technology readiness level (TRL) for blanket breeding remains relatively low. The breeding blanket encompasses the plasma and must operate at temperatures nearing 700 °C [1]. At such temperatures, tritium can rapidly permeate most structural materials. The blanket plays a critical role in tritium production, heat removal, plasma shielding, and providing a protective first wall. It must satisfy requirements related to material compatibility, structural integrity, and long-term support. A comprehensive examination of the implications of the tritium fuel cycle and the specific research and development (R&D) requirements can be found in "Bringing Fusion to the U.S. Grid" [4].

Examples of companies developing new solutions in tritium Fuel Cycle and blankets include:

Media and Process Technology Inc. has been working on the development of ultra-thin inorganic membranes for efficient fuel recovery and recycling in fusion power production.

Skyhaven Systems, LLC has been striving to improve hydrogen isotope separation, a critical aspect for the scalable operation of nuclear fusion. The company aims to enhance separation efficiency, reduce energy costs, and minimize the complexity of these systems.

Under the UKAEA's STEP initiative, researchers evaluated a novel breeding blanket design intended for fusion power stations. The assessment's core objective is to devise a design that can be manufactured using current methods while ensuring fuel self-sufficiency, effective heat removal, and shielding. The suggested design encapsulates breeding material within pebbles in a gas-cooled packed bed. Tritium and Helium generated in the breeding material are extracted from these pebbles and cooled externally. To enhance tritium production, a frontal multiplier and a back reflector were explored. This research offers a comprehensive insight into the design's material properties, configuration, neutronics analysis, thermal-hydraulics study, structural analysis preliminaries, safety considerations, and waste management. It lays foundational groundwork for STEP's potential commercial breeding blanket.

Magnets and Superconductors

Reducing the scale of a reactor has proven to be an effective strategy for lowering costs in reactor research and development, as demonstrated in nuclear fission [12]. In fusion, advances in high-temperature superconductors (HTS) and magnets have enabled the realization of more compact burning plasma, leading to the design of smaller reactors and their corresponding components and support systems, including those for diagnostics, heating current drive, and tritium breeding [1]. Continued progress in plasma confinement, facilitated by these enabling technologies, remains fundamental to the advancement of fusion energy.

The final fusion power plant necessitates magnet systems capable of operating under high temperatures and generating magnetic fields surpassing current industry capabilities. Ensuring high heat tolerance enables the integration of demountable joints in reactor construction and maintenance, potentially reducing the need for cryogens for temperature cooling. While HTS materials such as REBCO and Bi-2212 are ready for implementation in magnet development, iron-based superconductors also hold promise.

To drive HTS and magnet technology forward, the fusion sciences must actively incorporate HTS advancements into applications specific to fusion energy. FESAC emphasizes the need for research and development in coil pack designs tailored to fusion magnets, as well as further identification and characterization of HTS electrical and mechanical performance. Other technology gaps include cost reduction in fabrication processes and the development of radiation-tolerant insulation and high-strength structural materials for the magnet system [1]. The progress in material sciences will undoubtedly contribute to these endeavors.

Organisations developing improved superconducting technologies include:

Advanced Conductor Technologies LLC has embarked on a project to develop long-length CORC® cables and conductors, necessary to realize power generation through fusion and maintain U.S. leadership in high-energy physics, material research, and advanced cancer therapy.

Bridge 12 Technologies, Inc. has been exploring a liquid-helium-free high-temperature superconducting magnet design for high-frequency, high-power gyrotrons. These gyrotrons show promise in heating plasma in fusion power plants to produce net energy.

AMPEERS LLC has been working on a project aiming to establish a high-throughput manufacturing process for REBCO superconductor tapes, contributing to the success and commercial viability of future compact fusion reactors.

Tokamak Energy is constructing the Demo4 magnet system in a dedicated test facility. This system uses High-Temperature Superconducting (HTS) magnets in a tokamak configuration. The design aims to generate and test significant magnetic forces under conditions that mimic those in fusion power plants.

Lasers and optical technologies

Inertial confinement fusion (ICF) aims to utilize lasers, pulsed power technologies, and other innovative drivers to achieve compact fusion energy under high fuel density. While ICF poses significant challenges to the development of a cost effective fusion systems primarily due to its high energy requirements, advances in ICF technology could support lower FPP costs, new energy production approaches, and other fusion enabling technologies. As such, laser and ICF technology is fundamental to the fusion sciences.

Current laser technology requires high energy costs with relatively low efficiency. Recent advances come from the telecommunications industry in the form of low cost, high efficiency diode lasers [2]. Additional R&D will be required to bring ICF and laser technology to a readiness level that can be used by the fusion industry. To further these advances, FESAC recommends assisting existing ICF facilities such as the National Ignition Facility where a recent experiment released 70% of the energy required to trigger it [14].

Examples of companies developing lasers and optical technologies for fusion include:

GAMDAN Optics Inc. has been involved in a project aimed at scaling the seamless aperture of Lithium Tri-borate crystals for high-energy laser applications. The project will secure domestic accessibility to this critical material and advance U.S. interest in scientific research, fusion energy generation, and space communications.

TelAztec, LLC has been focusing on applying its Random AR nano-technology to fused silica and borofloat debris shields. The aim is to enhance the efficiency, power, durability, and lifetime of Inertial Fusion Energy laser drivers.

XUV Lasers Inc. has been engaged in a project to develop amorphous oxide interference coatings for Inertial Fusion Energy laser drivers. This technology aims to overcome the laser damage limitations of current interference coatings, thereby increasing the average power and operational lifetime of Inertial Fusion Energy lasers.

The EPSRC has granted £1.3 million for a three-year project led by Dr. Robbie Scott at the Central Laser Facility. This initiative is a collaborative effort with partners from institutions including the University of York, University of Warwick, and more from around the globe. The central objective is to assess the viability of the shock ignition approach to laser fusion. The CLF emphasized that this method could potentially lead to a more compact and economically efficient laser system compared to existing laser fusion ignition facilities.

Networking & Collaboration

A multitude of fusion energy projects, both public and private, are actively underway across the globe. Promoting collaboration among these diverse groups is crucial for accelerating progress in fusion energy science. This collaboration can be facilitated through the provision of shared resources such as experimental facilities, diagnostics, computational tools, and more, as well as through training programs and the exchange of knowledge. FESAC's 2020 report, "Powering the Future: Fusion and Plasmas," provides a comprehensive discussion of various network facilities that foster collaboration in the field [5]. These facilities encompass a wide range of expertise, spanning from laser technologies to magnetized plasma. By funding these programs, strategic investments can be made in advancing key fusion technologies. In cases where physical access to network facilities is not feasible, the development and promotion of digital network collaboration platforms and research tools can provide valuable assistance. These technologies and facilities should be regarded as supportive enabling technologies/capabilities, working in tandem with other crucial aspects of fusion energy research and development.

Other Supporting Technologies

There exists a vast array of enabling technologies that hold significant value in realizing the fusion energy system. While it may be impractical to comprehensively cover every industry or entity contributing to the advancement of fusion sciences, the resources mentioned throughout this section offer valuable insights into the prospects and requirements of these enabling technologies.

Among the notable supporting technologies that have yet to be mentioned are cybersecurity, waste management, advanced coolants, power plant designs, and integrated energy systems. Integrated energy systems have the potential to extend the applications of fusion energy beyond the energy grid, encompassing transportation, industrial purposes, and energy storage. However, it is important to note that this category, along with cybersecurity, plant designs, and fusion waste management, will assume greater significance once core fusion technology concepts have made further progress. The designs of fusion power plants will involve addressing challenges that extend beyond the core reactor, including regulation, licensing, remote handling, maintenance, safety systems, and the coordination of plant equipment [5]. Prior to construction, components and materials must undergo qualification and assessment for compatibility.

Global, international, and public research and development (R&D) programs, projects, and facilities have played a pivotal role in advancing enabling technologies to the current technology readiness level (TRL) we observe today. This progress has, in turn, enabled private companies to actively engage in enabling technology R&D. To expedite the commercialization of the fusion power plant, the American Physical Society Division of Plasma Physics Community Planning Process published its report, “A Community Plan for Fusion Energy and Discovery Plasma Sciences,” in 2019-2020 [15]. This report outlines a comprehensive plan devised by the U.S. fusion and plasma physics community to achieve fusion energy and advance plasma science.

An example of a company undertaking numerous projects developing enabling technologies for fusion is Ocem.

Ocem recently secured a contract worth nearly €8 million to design, produce, and set up the electronic systems (FDU, Fast Discharge Units) safeguarding the primary magnets of the new DTT fusion reactor, which is currently under development at the ENEA Research Centre in Frascati. This reactor aims to experiment with cutting-edge techniques to handle intense heat flows reminiscent of solar surfaces. Additionally, in collaboration with Ampegon, Ocem will extend its expertise to Japan, offering technical support for both the fusion reactor in Naka (JT-60SA tokamak) and the accelerator in Rokkasho (LIPAc-IFMIF). The two projects, combined, are valued at €5 million and focus on pivotal structures studying magnetic plasma confinement and testing fusion-specific high-strain materials. Furthermore, the Swiss firm Ampegon, procured by Gino Cocchi’s industrial group in 2019, is progressing with a €15.5 million project initiated with ITER almost a decade ago. This final phase, valued at roughly €5 million, entails the installation and initiation of high-voltage power supply systems for 16 gyrotrons in Cadarache, which are integral components for potent plasma heating.

Trinomics B.V.
Mauritsweg 44
3012 JV Rotterdam
The Netherlands

T +31 (0) 10 3414 592
www.trinomics.eu

KvK n°: 56028016
VAT n°: NL8519.48.662.B01

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