A Fusion Engine for Growth

A European Industrial Strategy for Fusion Energy

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Jack Moore, Policy Consultant, Clean Air Task Force

CATF CLEAN AIR TASK FORCE

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SECTION 1

Executive Summary

Introduction

Since the launch of the EUROfusion roadmap in 2018, the global fusion energy sector has undergone a dramatic transformation. The last seven years have seen the number of fusion energy companies globally more than quadruple, with influxes of private capital enabling multiple private fusion energy “unicorn” companies to emerge.[1] The growth of these fusion energy startups has enabled the pursuit of a breadth of fusion energy concepts, increasing the likelihood that one or more approaches will succeed in commercialising fusion energy. Multiple companies have put forth credible plans and partnerships to put fusion power on the grid.[2,3] This growth is underpinned by advances in enabling technologies, such as high temperature superconductors, as well as high-performance computing and Artificial Intelligence (AI), which are creating more economical fusion energy machine designs and accelerating overall progress. As a result, the timeline for fusion energy commercialisation has been redefined.

Concurrently, a broader consensus has taken shape within the European Union (EU) that industrial strategies for competitiveness in key sectors are essential to securing Europe’s future prosperity and global leadership. To that end, last year, the European Commission commissioned Mario Draghi to prepare a competitiveness strategy for Europe. Within this report, *“The Future of European Competitiveness*, Draghi specifically calls for a new strategy on fusion energy.[4]

[1] Fusion Industry Association. The global fusion industry report 2024. Washington, DC: Fusion Industry Association; 2024

[2] 2024, December 19. *Virginia selected to host World’s first commercial fusion plant, a critical step forward for Fusion Technology Innovation*. Clean Air Task Force. https://www.catf.us/2024/12/virginia-selected-host-worlds-first-commercial-fusion-plant-critical-step-forward-fusion-technology-innovation/

[3] *TVA developing plans with type one energy for Fusion Plant*. World Nuclear News. (2025). https://www.world-nuclear-news.org/articles/tva-signs-up-for-type-one-energy-fusion-plant

[4] Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations*. European Commission.

With a revised fusion energy roadmap expected later this year,[5] it is incumbent upon the EU to incorporate a true industrial strategy into this roadmap to build a fusion energy sector that can compete on the global stage.

Europe has the scientific expertise and infrastructure to lead in fusion energy. What is needed now is the political commitment and targeted policies to turn that potential into commercial reality. The window for action is open, but it will not remain so forever. Global competitors are pursuing fusion energy in earnest, and without sustained industrial action and commitments, Europe will be left behind despite decades of fusion energy leadership. The recommendations in this report constitute a foundation for a fusion energy industrial strategy. They are not a technical roadmap; rather, they are intended to serve as the foundation of a broad strategy towards a new approach to fusion energy upon which future technical roadmaps can be built. They provide a clear path to convert decades of public investment into a thriving fusion energy industry capable of reigniting Europe's engine for growth.

Fusion Energy for Competitiveness

The European Commission's recent report *"The Future of European Competitiveness*, authored by Mario Draghi, finds that Europe's lack of productivity growth threatens its ability to maintain its social model. "Europe's core values—prosperity, equity, freedom, peace, and democracy," the report warns, "are at risk. Only by fostering growth and innovation can Europe sustain these values without compromise."[6] The Draghi Report and the subsequent Competitiveness Compass find that Europe has the assets and talent to lead in the global economy of tomorrow, but that structural, governance weaknesses are holding back the EU from harnessing this innovative capacity for productivity growth.[7]

The Draghi report, and the subsequent Competitiveness Compass roadmap built off of its recommendations, outlines three key actions to drive productivity growth: **closing the innovation gap which has emerged between Europe and other global competitors, leveraging decarbonisation as a competitive opportunity for Europe, and increasing security by reducing dependencies**.[8] In particular, the report stresses the importance of identifying early-stage industries in which Europe **both holds an innovative edge, and which can strengthen the European position across these three key action areas. A competitive fusion energy industry would be capable of contributing to all three pillars**.

However, fusion energy can only contribute meaningfully to these strategic priorities if Europe actually *can* develop a globally competitive private fusion energy sector. This report uses a SWOT analysis to assess whether Europe's fusion energy ecosystem possesses such an "innovative edge" as identified in the Draghi report to be an industry capable of contributing to these priorities. Table ES-1 presents our findings.

5 Righi, E. (2025). *The state and prospects of Fusion Energy Workshop - Event*. IEA. https://www.iea.org/events/the-state-and-prospects-of-fusion-energy-workshop

6 Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations*. European Commission.

7 Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations*. European Commission.

8 European Commission. (2025, January 29). *A competitiveness compass for the EU* (COM(2025) 30 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52025DC0030

Table ES-1

Strengths	Weaknesses	Opportunities	Threats
• The ITER Project and its Supply Chain • Strong R&D Infrastructure • Existing Private Fusion Energy Startups • Fusion Energy Talent and Education • The Fusion for Energy (F4E) Joint Undertaking (JU)	• Overlapping and Competing Governance Structure • EUROfusion Roadmap not Adapted to Private Sector Timeline • Low Levels of Private Sector Investments in Fusion Energy Startups • Lack of Regulatory Certainty • Knowledge Management Deficits	• European Investment Bank • Fusion Energy Export Markets • EU Climate Action Commitments	• Brain Drain • Industry Flight • Falling too far behind US and China to Compete

The findings of our SWOT analysis show that Europe's fusion energy ecosystem has many of the inherent advantages necessary to be globally competitive. The necessary infrastructure and talent for fusion energy leadership are clearly present, with an existing world-class supply chain as a result of the Fusion for Energy (F4E) Joint Undertaking's (JU) procurements for the ITER project. However, overlapping and competing governance structures lacking clear goals, inefficient access to public-private partnerships, a lack of regulatory certainty, amongst other factors, are currently impeding Europe's fusion energy startups' ability to compete on the global stage. With the EU currently preparing a new overall fusion energy strategy,[9] it is essential that it include an industrial strategy that aligns fusion enerrgy policy and governance with Europe's broader competitiveness goals, in order to support fusion energy developers in narrowing the innovation gap. In doing so, a thriving European fusion energy industry could help reignite the engine of European growth.[10] Our recommendations to do so are as follows.

Key Policy Recommendations

Recommendation A: Shifting the European Fusion Energy Programme from a Sequential Model to KET-Based Roadmap

The revised fusion energy strategy should move away from the current sequential, DEMO-focused roadmap, and adopt a Key Enabling Technologies (KET)-based strategy prioritising commercially relevant R&D. This would reorient the public research ecosystem to support the competitiveness of fusion energy startups in a technology-neutral way by closing scientific and technology gaps required for commercial fusion power plants as well as those required for a public sector DEMO project, rather than a sole focus on the closing of gaps for the DEMO design. A KET approach would promote flexibility and competition on technical merit in fusion energy development.

[9] Righi, E. (2025). *The state and prospects of Fusion Energy Workshop - Event*. IEA. https://www.iea.org/events/the-state-and-prospects-of-fusion-energy-workshop

[10] European Commission. (2025, January 29). *A competitiveness compass for the EU* (COM(2025) 30 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52025DC0030

Recommendation B: Establish Fusion for Energy as the Sole Fusion Governance Body in Europe

The European fusion energy ecosystem suffers from an overlapping and competing governance structure which prevents a coordinated vision to accelerate the commercialisation of fusion energy. The Fusion for Energy (F4E) Joint Undertaking (JU) should be expanded to function as the singular public governance body responsible for coordinating fusion energy research, industrial engagement, and commercialisation efforts across Europe, incorporating the private sector—both start-ups and industrial suppliers—as co-leaders in its decisions and priorities.

Recommendation C: Retrofit the Capabilities of Existing Public Sector Institutions' Missions to Support a KET-Based Roadmap

Public fusion institutions and laboratories should be reoriented in mission to support near-term commercialisation under a KET-based roadmap. ITER's capabilities should be utilised to support private sector commercialisation. Other facilities should be similarly directed to align experimental priorities with the KET requirements for industry to successfully commercialise.

Recommendation D: Establishing an Innovation Partnership Public-Private Partnership Through Fusion for Energy

Europe should establish a cohesive Public-Private Partnership (PPP) programme through F4E's "Innovation Partnership" mechanism. These partnerships would provide cost sharing with fusion energy companies to support their commercialisation pathways, enable shared access to experimental facilities, support collaborative development of key enabling technologies, and ensure that Europe's fusion energy R&D investments contribute directly to commercial success.

Recommendation E: Establish PPP IP Rights Which Support Competitiveness

IP management frameworks should be set up to favour, where possible, the private sector fusion energy party. This will ensure that public investments in fusion energy research contribute to European productivity growth by preventing innovation from becoming siloed and enabling it to reach the marketplace. Fusion for Energy's Technology Development Programme the industry to own the IP generated in the partnership, which could serve as a model for a larger programme.

Recommendation F: Comprehensive Mapping of the European Fusion Energy Supply Chain in the Context of New Threats

F4E should continue its comprehensive mapping of the European fusion energy supply chain to identify overreliance on single-source suppliers or specific regions, including those previously considered stable. F4E should subsequently catalyse action to smooth any such supply chain kinks to safeguard Europe's fusion energy industry against future disruptions.

Recommendation G: Establishing Regulatory Principles Separating Fusion Energy from Fission Energy

Europe must develop regulatory principles separating fusion energy regulation from fission regulation, enabling member states to establish generally aligned regulatory frameworks for fusion energy to increase regulatory certainty for fusion energy developers.

Recommendation H: Codifying Fusion Energy as a Strategic Green Technology Across EU Legislation

Fusion energy should be explicitly supported in EU legislation wherever possible as a strategic priority. We recommend specifically that it be recognised in the EU Green Taxonomy and the Net-Zero Industry Act (NZIA) as a strategic green asset separate from other nuclear technologies. Clear inclusion in more climate initiatives would position fusion energy as a central pillar of Europe's clean energy and industrial strategy.

SECTION 2

Fusion Energy as a Driver of European Competitiveness

Incubating Breakthrough Innovation:

The Draghi report identifies Europe's innovation gap as the most pressing challenge in reversing the productivity growth stagnation which has occurred over the past 25 years.[11] Breakthrough innovations in high-growth sectors are essential for sustained GDP growth to uphold Europe's core values, yet its industrial structure remains caught in the "middle technologies trap," prioritising mature industries with limited growth potential.[12] The problem, the Draghi report argues, is not a lack of ideas or ambition, but rather, that "*innovation is blocked at the next stage: we are failing to translate innovation into commercialisation.*"[13]

Fusion energy is precisely the type of breakthrough innovative sector the Draghi report identifies as having the potential to break this trap. The past decade has seen unprecedented progress in fusion energy technology development, transforming the sector from a long-term research endeavour into an industry with high-growth potential in the short-to-medium term.[14] Scientific breakthroughs, such as the achievement of scientific breakeven at the U.S. National Ignition Facility (NIF) and record energy outputs from the Joint European Torus (JET), have demonstrated that the fusion energy industry is clearly making progress towards commercial viability.[15] Concurrently, enabling technologies are increasing the economic viability of fusion energy as well as accelerating commercialisation timelines. In particular, the development of high temperature superconducting (HTS) tapes, now available at an industrial scale, enables creation of stronger magnetic fields, allowing for more compact and cost-effective magnetic fusion energy designs. Furthermore, High Performance Computing and AI are reducing design iteration cycle timelines through techniques such as surrogate modelling, as described in CATF's recent report on the intersection of fusion energy and AI.[16]

As a result of these advancements, globally, the translation from innovation to commercialisation which Draghi describes is underway. At least $8 billion in private fusion energy equity investments has been committed or received, with most funding arriving since 2020.[17] This influx of capital has diversified the fusion energy landscape, supporting companies pursuing a wide variety of concepts.[18] This diversity supports a

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11 Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations*. European Commission.

12 Fuest C, Gros D, Mengel PL, Presidente G, Tirole JJ. EU innovation policy: How to escape the Middle Technology Trap. ifo Institute-Leibniz Institute for Economic Research at the University of Munich; 2024.

13 Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations*. European Commission.

14 FusionX. (2025). Funding Fusion: The State of the Market. Retrieved 2025.

15 Tischler, K. (2024, February 8). *Breaking new ground: Jet tokamak's latest fusion energy record shows mastery of fusion processes.* EUROfusion. https://euro-fusion.org/eurofusion-news/dte3record/.

16 Clean Air Task Force, EPRI, & Fusion Advisory Services. (2024). *A Survey of Artificial Intelligence and High Performance Computing Applications to Fusion Commercialisation.* Clean Air Task Force.

17 Tarasov, K. (2025, March 16). *How the U.S. is losing ground to China in nuclear fusion, as AI Power Needs Surge.* CNBC. https://www.cnbc.com/2025/03/16/the-us-is-falling-behind-china-in-nuclear-fusion-needed-to-power-ai.html#:~:text=Since%20then%2C%20private%20investment%20in,are%20based%20in%20the%20U.S.

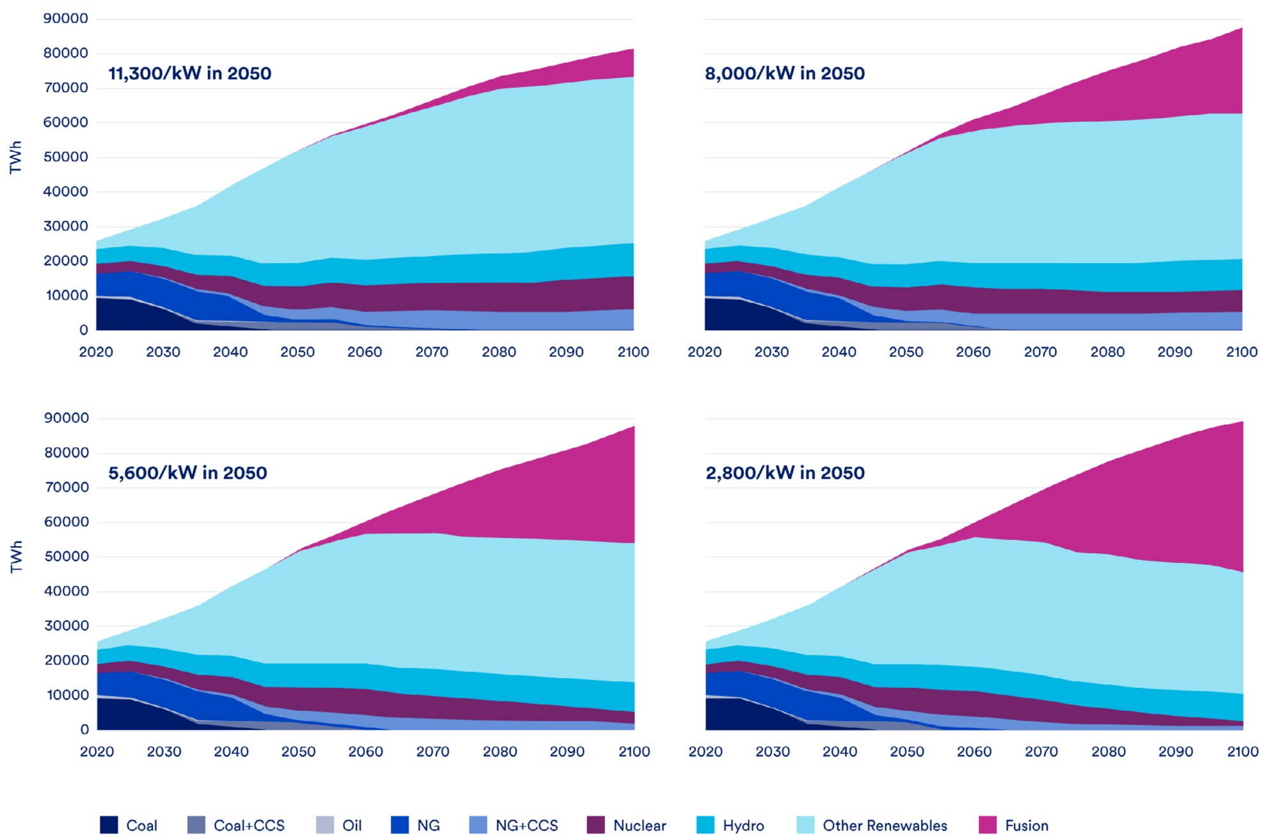
18 Fusion Industry Association. The global fusion industry report 2024. Washington, DC: Fusion Industry Association; 2024

"many shots on goal" strategy, increasing the likelihood of commercialisation and mitigating risk through the investigation of multiple avenues to fusion energy. Reflecting this growth, the number of active fusion energy companies has more than quadrupled since 2017, with at least 56 fusion energy machine developers currently operating.[19,20] Industry estimates that the first fusion energy startups will demonstrate energy breakeven in the late 2020s, that the first pilot plants will go on the grid in the early-to-mid 2030s, with the industry commercially maturing by the 2040s.[21]

A recent fusion energy deployment study conducted by the MIT Energy Initiative in conjunction with the MIT Plasma Science and Fusion Center suggested that, by the second half of the century, fusion energy could represent a significant share of global energy supply. The report modelled four different viable overnight costing scenarios for fusion power plants and the resulting penetration of fusion energy in globalel ectricity markets. The results ranged between less than 10%, to approximately 50% by 2100.[22]

Figure 1: Projected Fusion Penetration in the Global Electricity System Under Different FPP Cost Assumptions for a 1.5° Celsius Stabilisation Pathway Scenario

Source: MIT Energy Initiative[23]



[19] Fusion Industry Association. The global fusion industry report 2024. Washington, DC: Fusion Industry Association; 2024

[20] *Organisations.* Organisations | Fusion Energy Base. (2025). https://www.fusionenergybase.com/organisations

[21] Fusion Industry Association. The global fusion industry report 2024. Washington, DC: Fusion Industry Association; 2024

[22] MIT Energy Initiative, Whyte, D., Armstrong, R., & MIT Plasma Science and Fusion Center. (2024). *The Role of Fusion Energy in a Decarbonized Electricity System.* MIT

[23] MIT Energy Initiative, Whyte, D., Armstrong, R., & MIT Plasma Science and Fusion Center. (2024). The Role of Fusion Energy in a Decarbonized Electricity System. MIT

If fusion energy companies are able to capture a significant share of the global electricity market, as modelled in the study, they could tap into massive growth opportunities in a rapidly expanding market already valued at over $1 trillion.[24,25] If Europe's fusion energy startups can participate in this growth, it could enable the fusion energy industry to drive considerable shares of the productivity growth required to close the innovation gap identified in the Draghi report.

Leveraging Decarbonisation for Growth:

The Draghi report also argues that while securing reliable and affordable clean energy is a planetary necessity, it must not impede Europe's growth but instead be harnessed as an opportunity. Fusion energy would address both challenges with its firm, zero-emission power, making it a viable replacement for fossil fuel-based firm energy infrastructure as a complement to weather-dependent renewable energy resources. Studies by energy system researchers and grid operators indicate that future low-carbon grids systems relying solely on renewables, even with storage solutions, would be less reliable and much more costly than those incorporating firm energy sources.[26] Fusion energy's siting flexibility and intrinsic safety further increase its capability to contribute to a more stable and lower-cost future low-carbon grid.[27]

Furthermore, fusion energy's fuel abundance and energy density, which is million times that of an equivalent mass of fossil fuels, suggests that fusion energy could support the European market in achieving not only energy transition but energy addition.[28] Fusion energy is particularly suited for the energy addition required for energy-intensive data centres supporting AI expansion.[29] CATF's recent report on the intersection of AI and fusion energy notes that fusion energy, once commercialised, may be an ideal solution for data centres due to its zero-carbon, firm power with a safety profile enabling deployment near urban centres.[30] Beyond electricity generation, fusion energy may also be able to provide zero-carbon industrial heat necessary for processes such as desalination, direct air capture, and district heating, which can also improve the economics of fusion energy plants through cogeneration.[31] It may also contribute to hydrogen production, ammonia synthesis, and the decarbonisation of steel refining and building heating.[32] These benefits of fusion energy deployment would make good on the promises of decarbonisation by simultaneously enabling energy security and industrial growth while establishing a competitive clean energy economy for Europe.

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24 IEA. (2024). *Growth in global electricity demand is set to accelerate in the coming years as power-hungry sectors expand – news. IEA.* https://www.iea.org/news/growth-in-global-electricity-demand-is-set-to-accelerate-in-the-coming-years-as-power-hungry-sectors-expand

25 Global Electricity Generation Market Value 2031 | statista. (2025). https://www.statista.com/statistics/1456985/electricity-generation-market-value-worldwide/.

26 MIT Energy Initiative, Whyte, D., Armstrong, R., & MIT Plasma Science and Fusion Center. (2024). *The Role of Fusion Energy in a Decarbonized Electricity System.* MIT.

27 White, P. (2024). Testimony before the U.S. Senate Committee on Energy and Natural Resources: Testimony of Dr. Patrick White.

28 Barbarino, M., & Atomic Energy Agency, I. A. E. (2025, April 7). *What is nuclear fusion?*. IAEA. https://www.iaea.org/newscenter/news/what-is-nuclear-fusion

29 EPRI. Powering Intelligence: Analyzing Artificial Intelligence and Data Center Energy Consumption; 2024

30 Clean Air Task Force, EPRI, & Fusion Advisory Services. (2024). *A Survey of Artificial Intelligence and High Performance Computing Applications to Fusion Commercialisation.* Clean Air Task Force.

31 Handley, M. C., Slesinski, D., & Hsu, S. C. (2021). Potential early markets for fusion energy. *Journal of Fusion Energy, 40*(2), 18.

32 Handley, M. C., Slesinski, D., & Hsu, S. C. (2021). Potential early markets for fusion energy. *Journal of Fusion Energy, 40*(2), 18.

Increasing Security to Reduce Dependencies:

The Draghi report defines increasing security by reducing dependencies as a "precondition" for sustained growth. Today, Europe relies on fossil fuel imports for nearly 2/3rds of its energy supply.[33] This energy dependency creates a clear chokepoint, increasing the risk of coercion or exploitation by geopolitical adversaries. While the EU has responded to these pressures through the RePowerEU plan, these measures alone will likely not be sufficient to establish true energy independence.[34] This reliance also has the effect of increasing energy prices for European consumers, in particular retail customers, who face 2-3 times higher electricity costs as opposed to U.S. and Chinese competitors.[35] In conjunction, these prices are often volatile, impeding the operations and therefore the competitiveness of European firms.

Fusion energy, however, offers the potential for an abundant domestic energy supply. Deuterium-Tritium (DT) fusion energy machines will require the abundant fuel resource of deuterium, which can be extracted from seawater at scale, and tritium, which is planned to be bred from lithium blankets within fusion energy machines. The near-unlimited, geographically distributed fuel resources necessary for fusion energy therefore offers an opportunity to secure European energy independence, as the ability to deploy fusion energy will be determined by technological know-how, not resource endowments.[36] Moreover, as a result of the ITER project and the Fusion for Energy (F4E) Joint Undertaking (JU), the EU leads the world in fusion energy component production, resulting in a world-class European fusion energy supply chain. Continued supply chain growth will be necessary to serve a commercial industry, but today, Europe's supply chain is well-positioned to avoid supply chain chokepoints. In all, the successful widespread deployment of commercial fusion energy would enable stable energy supply for Europe, protecting the continent from geopolitical coercion and economic shocks threatening long-term growth.

[33] European Commission. (2025, January 29). *A competitiveness compass for the EU* (COM(2025) 30 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52025DC0030

[34] Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations*. European Commission.

[35] Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations*. European Commission.

[36] Note: Tritium breeding is still at a low technology readiness level. In-situ breeding still needs to be developed at scale.

SECTION 3

Europe's Fusion Energy Sector SWOT Analysis

Clearly, a successful fusion energy industry aligns with the three strategic priorities outlined in the Draghi Report to drive productivity growth in Europe. However, for fusion energy to contribute to this growth, Europe's fusion energy industry must be globally competitive. Indeed, the Draghi report argues that Europe should only cultivate industries with potential impact in these strategic areas if they have existing innovative advantages to make competition realistic.

The following section presents a SWOT analysis (Strengths, Weaknesses, Opportunities, and Threats) of the current European fusion energy ecosystem. This evaluation by Clean Air Task Force assesses whether the European fusion energy sector is sufficiently well-positioned to compete globally to make its success a priority for the European Union.

Strengths

ITER Project

The ITER project is the fundamental competitive advantage of the European fusion energy industry. ITER is a 33-country international collaboration constructing a tokamak[37] designed to achieve an energy gain ratio (Q) greater than 10 in order to demonstrate the feasibility of fusion power. The organisation counts the European Union, the United States, Russia, China, India, Korea, and Japan as its members.[38] However, with the project sited in Cadarache, France, Europe as project host has a special stake in its success. ITER is specifically designed to answer the critical scientific and technological questions necessary for commercial fusion energy. In particular, ITER diagnostics will uncover

Table 1

Strengths	Weaknesses	Opportunities	Threats
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37 A tokamak is a fusion energy machine which uses magnetic fields to contain plasma in a toroidal-shaped chamber.

38 Q is the measure of the ratio of fusion energy output to the input of energy to start and maintain the reaction.

key experimental information on alpha heating, or the self-heating of the plasma by alpha particles generated through the fusion process. This phenomenon creates a "burning plasma," enabling the reaction to become self-sustaining and increasing energy yields. The Draghi Report specifically identifies the "leveraging [of] the ITER project" as the best pathway to achieve a stable and predictable fusion energy ecosystem for industrial innovation in Europe.[39]

The momentum of fusion energy startups towards commercialisation, combined with ITER's announcement of project delays, indicates that ITER will likely not be the first project to break energy breakeven.[40] However, the project still represents a clear, reliable pathway to achieving energy breakeven with a magnetic fusion energy approach,[41,42] and its advanced diagnostics will offer key diagnostic data to support not only tokamak designs, but projects pursuing a range of magnetic fusion energy approaches.[43]

ITER also plays a key role in cultivating European talent for the fusion energy sector. Although ITER is a global collaboration, nearly 70% of ITER's 1,100-member staff is European. ITER has therefore developed a ready-made fusion energy workforce with direct expertise in planning for the lifecycle of an energy-breakeven fusion energy plant capable of deuterium-tritium operations, from design all the way to decommissioning.[44] This vests within Europe unmatched technical experience in fusion energy science and engineering.[45] In recent years, these competencies have grown across key areas, according to a recent review of Europe's fusion energy human resources.[46] ITER is also partnering with the private sector to provide access to its developed expertise through its Private Sector Fusion Engagement Project. This initiative aims to formally document the lessons learned throughout ITER's operations, particularly in construction and licensing, to preserve them for future fusion energy projects.[47] As part of this programme, ITER is opening access to its documentation. The organisation is also working to open source its Integrated Modelling & Analysis Suite (IMAS),[48] as well as on a private sector secondment programme to embed industry professionals within ITER, fostering knowledge transfer out of the project into industry. ITER now hosts an annual Private Sector Fusion Workshop onsite, bringing together private sector actors to ensure the organisation can better understand and respond to industry needs.[49]

The ITER project has also resulted in a world-class supply chain for fusion energy component manufacturing emerging in Europe. With the **Fusion for Energy** (F4E) European Joint Undertaking (JU) responsible for 45% of ITER's construction, including component procurement and site development, fusion energy manufacturing and construction has already become a profitable industry in Europe. Between 2008 and 2019, ITER's activities generated EUR 1.7 billion in gross value added and created nearly 29,500 direct and indirect jobs, expanding fusion energy expertise beyond ITER's own workforce and developing manufacturing know-how to support a broader fusion energy component industry.

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39 Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations*. European Commission.

40 Keating, D. (2024, October 28). *Can Europe get fired up to compete globally on nuclear fusion?.* Euractiv.

41 Annex A provides background knowledge on the specifics of different types of fusion approaches.

42 Full Committee Hearing To Examine The Federal Government's Role In Supporting The Commercialisation Of Fusion Energy. U.S. Senate Committee on Energy and Natural Resources. 2022. Available from: https://www.energy.senate.gov/hearings/2022/9/full-committee-hearing-to-examine-the-federal-government-s-role-in-supporting-the-commercialisation-of-fusion-energy

43 Full Committee Hearing To Examine The Federal Government's Role In Supporting The Commercialisation Of Fusion Energy. U.S. Senate Committee on Energy and Natural Resources. 2022. Available from: https://www.energy.senate.gov/hearings/2022/9/full-committee-hearing-to-examine-the-federal-government-s-role-in-supporting-the-commercialisation-of-fusion-energy

44 Fasoli, A., Becoulet, A., Belonohy, E., & Vecchio, A. (2023). (publication). *The 2023 HUMAN RESOURCES (HR) SURVEY FOR THE EUROPEAN FUSION RESEARCH PROGRAMME. EUROfusion.*

45 ITER Organisation. (2023). (rep.). *Report on Human Resources.* Cadarache, France.

46 Fasoli, A., Becoulet, A., Belonohy, E., & Vecchio, A. (2023). (publication). *The 2023 HUMAN RESOURCES (HR) SURVEY FOR THE EUROPEAN FUSION RESEARCH PROGRAMME. EUROfusion.*

47 Admin. (2024, December 19). *ITER enters a shared-information era.* ITER. https://www.iter.org/node/20687/iter-enters-shared-information-era

48 IMAS is the collection of software that will be used for all physics modelling and analysis at ITER.

49 ITER. (2025). *Iter Private Sector Fusion Workshop.* https://www.iter.org/2nd-iter-private-sector-fusion-workshop

A European Commission report found that for every job created within ITER, another emerged in its supply chain or through secondary economic activity, building the industrial know-how needed to support a fusion energy industry supply chain.[50]

Going forward, scaling this supply chain alongside the global expansion of fusion energy deployment presents a distinct growth opportunity for Europe. European industrial firms have developed niche expertise in manufacturing specialized fusion energy components through their involvement in ITER and other major public-sector projects that will be required for commercial fusion efforts around the world. If European suppliers can establish leadership and expertise in the production of key systems and components, they can capture value from the global fusion energy industry to contribute to European productivity growth—regardless of where the fusion energy companies themselves are headquartered.[51] The supply chain developed for ITER also contributes to reducing Europe's dependencies in fusion energy. As global trade barriers appear to be rising, Europe is less vulnerable to this challenge than other regions, as ITER procurement through F4E has already anchored a specialised industrial base for fusion energy component manufacturing. While this supply chain will have to be scaled up to support a mature commercial fusion energy industry, the foundations to ensure stable and friendly supply chains are present. Therefore, unlike many other industries, the fusion energy sector is unlikely to require a major overhaul of its supply chains to remain secure in a shifting geopolitical landscape.

Strong R&D Infrastructure

Although ITER has not yet begun operations, Europe's other R&D facilities are already the global standard for fusion test beds. Historically, the **Joint European Torus, or JET**, has been the "flagship device" of the EU fusion energy programme. JET is the most powerful fusion energy machine ever designed, setting the record of fusion power output in 2022 at 69 MJ,[52] and is the largest magnetic fusion energy machine with tritium handling capacity to date. Although the facility was designed to test plasma scenarios, impurity control, and power exhaust strategies for ITER, its results have also provided key data to inform commercial fusion power plant designs. JET experiments demonstrated sustained high fusion power plasmas, refined disruption mitigation techniques, and validated key plasma control methods, all of which will particularly inform commercial machine designs which will use deuterium-tritium (D-T) fuel mixtures. JET's work on plasma-facing components and materials testing provided essential data on component longevity and regulatory compliance which informs commercial approaches today.[53] It has also served as a breeding ground for much of the fusion energy workforce development thus far in Europe alongside ITER; although JET recently concluded operations, its experimental legacy is responsible for much of the fusion energy expertise and competences in Europe today.[54] Europe also boasts **unparalleled stellarator R&D infrastructure**. Unlike tokamaks, stellarators use twisted magnetic fields to confine plasma without relying on a current, which reduces instabilities but requires highly complex magnetic coil designs to generate the precise fields necessary for operation. For decades, the intricate engineering needed for these coils made stellarator designs seem impractical for commercial fusion energy production.[55] These assumptions were overturned by the construction and operations of **Wendelstein 7-X, a stellarator built at the Max Planck Institute of Plasma Physics**. Over the last decade, the device has set records for electron temperature, plasma density, and energy confinement time, and achieved the highest fusion energy triple product ever recorded in a stellarator.[56]

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50 Directorate-General for Energy (European Commission), Markit, I., Lgi, Erim, Chauvet, Heger, & Wiegert. (2021, January 1). *Follow up study on the economic benefits of ITER and BA projects to EU Industry.* Publications Office of the EU. https://op.europa.eu/en/publication-detail/-/publication/3db11048-6a89-11eb-aeb5-01aa75ed71a1/language-en

51 Cardozo NL. Economic aspects of the deployment of fusion energy: the valley of death and the innovation cycle. Philosophical Transactions of the Royal Society A. 2019 Mar 25;377(2141):20170444.

52 Tischler, K. (2024, February 8). *Breaking new ground: Jet tokamak's latest fusion energy record shows mastery of fusion processes.* EUROfusion. https://euro-fusion.org/eurofusion-news/dte3record/

53 Mailloux, J., Abid, N., Abraham, K., Abreu, P., Adabonyan, O., Adrich, P., ... & Butcher, D. (2022). Overview of JET results for optimising ITER operation. *Nuclear Fusion, 62*(4), 042026

54 Belanohy, E. (2023). (rep.). *EUROfusion Knowledge Management Strategy.* EUROfusion.

55 Kupp, M., & Köhn-Seemann, A. (2023.). *What the return of the stellarator means for fusion energy.* World Economic Forum. https://www.weforum.org/stories/2023/06/the-renaissance-of-the-stellarator-what-this-means-for-fusion-energy/.

56 Szabolics, T. (2024, September 20). Wendelstein 7-X Starts new experimental campaign. EUROfusion. https://euro-fusion.org/member-news/wendelstein-7-x-starts-new-experimental-campaign/

It also demonstrated the precise geometric tolerances required for modular coils, advanced detachment techniques to minimise heat loads on material surfaces, and achieved the highest energy turnover of any fusion energy device, sustaining an eight-minute plasma discharge with 1.3 GJ of injected heating energy.[57] Its success has positioned Europe at the forefront of stellarator development, providing critical insights for future commercial fusion energy designs. Indeed, the United States has recognised the absence of a comparable stellarator experiment as a gap in its long-term fusion energy strategy. Access to Wendelstein 7-X has, in particular, supported private European stellarator startups. Proxima Fusion is a direct spinout from work done at W7-X.[58,59]

Europe's **Divertor Tokamak Test** (DTT) is another infrastructural R&D advantage for the European ecosystem. DTT, located in Frascati, Italy, investigates the feasibility of divertor designs for plasma exhaust in commercially relevant plants. Any commercial fusion energy concept using deuterium-tritium fuel will need to manage exhaust by handling heat and particle flux from the plasma without significant erosion or component degradation. Specifically, these plants will require divertors tolerant of heat loads up to 60 MW/m²,[60] far beyond what ITER's technology can handle.[61] DTT will test solutions such as liquid metal divertors and advanced magnetic configurations to spread or mitigate heat loads, in order to determine a design which can ensure materials can survive fusion power plant conditions.[62] The consortium approach taken by DTT, operating as a public-private partnership, serves as a model for effective collaboration between the public and private sectors. DTT Head Francesco Romanelli explained, "Converging industry, academia, and public sector research institutions is the pathway to obtaining a fusion power plant sooner than expected."[63]

The **Broader Approach (BA) agreement**, which was signed in 2006 between Europe and Japan, is an agreement to support specific projects to contribute to the research, development, and testing of technologies for the planned DEMO device. Specifically, these projects are designed to research systems which will be required for commercialisation in the current EUROfusion Roadmap which ITER will not cover or will complement relevant ITER activities.[64] These activities consist of three projects; The Satellite Tokamak Programme Project, JT-60SA, The International Fusion Energy Research Centre (IFERC), and the Engineering Validation and Engineering Design Activities for the International Fusion Materials Irradiation Facility (IFMIF/EVEDA), which is to be followed by the IFMIF-DONES facility (International Fusion Materials Irradiation Facility- DEMO-Oriented Neutron Source). Europe's operation of these projects (in conjunction with Japan) provide key R&D for future commercial fusion energy devices, as well as to develop specific skills required for a fusion energy workforce.

JT60-SA, located in Japan but built and operated jointly between Japan and the EU, is currently the world's largest operational superconducting tokamak, and was built to investigate plasma scenarios and control strategies to support ITER as well as investigating key physics and engineering issues for DEMO machines.[65] These experiments will focus on **plasma phenomena such as stable high-current operation, disruption mitigation, real-time control of sawtooth periods, neoclassical tearing modes, and energetic particle effects**.

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57 Szabolics, T. (2024, September 20). Wendelstein 7-X Starts new experimental campaign. EUROfusion. https://euro-fusion.org/member-news/wendelstein-7-x-starts-new-experimental-campaign/.

58 *How the most advanced stellarator in the world set the stage for commercial fusion.* Proxima Fusion. (2025). https://www.proximafusion.com/press-news/how-the-most-advanced-stellarator-in-the-world-set-the-stage-for-commercial-fusion

59 Clery, D. (2022). *Twisty device explores alternative path to fusion. Science.*

60 60 MW/m² is approximated from DEMO design requirements. The fluxes of different private fusion companies' concepts will vary, but most magnetic fusion energy concept will exceed ITER fluxes.

61 Moore, J. (2024, July 3). *Public/private consortium is building the DTT Tokamak.* ITER. https://www.iter.org/node/20687/public/private-consortium-building-dtt-tokamak

62 Moore, J. (2024, July 3). Public/private consortium is building the DTT Tokamak. ITER. https://www.iter.org/node/20687/public/private-consortium-building-dtt-tokamak

63 Moore, J. (2024, July 3). Public/private consortium is building the DTT Tokamak. ITER. https://www.iter.org/node/20687/public/private-consortium-building-dtt-tokamak

64 Dzitko, H., Barabaschi, P., Cara, P., Carin, Y., Lorenzo, S. C., Davis, S., … & Yagi, M. (2024). Overview of Broader Approach activities. *Fusion Engineering and Design, 201,* 114259.

65 *JT-60SA.* JT60SA. (2025). https://www.jt60sa.org/wp/.

High-beta plasma scenarios will also be explored, addressing current drive optimisation, transport and turbulence studies, and edge-localised mode suppression. Later phases will expand pulse duration, heating power, and divertor performance to achieve steady-state, self-organising plasmas beyond ideal MHD stability limits. JT-60SA will also conduct metal-wall experiments to refine power and particle exhaust control.[66]

These expected JT60-SA contributions "to smooth and reliable implementation of ITER experiments", according to the JT60-SA design team, can also contribute to smooth and reliable demonstration and power plant development for European private fusion energy companies.[67] JT-60SA is thus among the world's most valuable facilities for fusion research supporting commercialisation, and Europe's joint operation of this facility provides a clear competitive advantage for its fusion energy industry. As a follow up to the Broader Approach's IFMIF EVEDA programme, the IFMIF-DONES facility currently being built in Granada, Spain will be the world's first fusion-relevant prototypic neutron source, using a particle accelerator to direct a continuous-wave deuteron (D^+) beam at a liquid lithium target. IFMIF-DONES will generate neutrons replicating the flux expected in future commercial fusion energy machines, providing the first direct data on material behaviour under such conditions. The facility will serve as an open testing platform for materials deemed critical by the European fusion energy community.[68,69]

In parallel, Europe has initiated design work on a Volumetric Neutron Source (VNS), a 14 MeV neutron facility intended to test and validate tritium breeding solutions. This capability would enable the validation of tritium breeding systems required for commercially viable fusion energy machines using a deuterium-tritium fuel mix.[70] If Europe successfully builds a VNS, it will be a clear competitive advantage for the commercial fusion energy sector.

IFERC has provided supercomputing resources to the European fusion energy community since 2012, supporting fusion plasma simulations, experimental data analysis, ITER operation modelling, and DEMO design contributions. From 2012 to 2016, these resources were powered by the Helios supercomputer, which was later replaced by HPC JFRS-1. Currently, half of JFRS-1's computing time and resources are allocated by QST to Broader Approach simulation projects selected by IFERC.[71] Additionally, EUROfusion contributes computing resources through the EU HPC Marconi, further supporting these simulation efforts.[72] IFERC also oversees the DEMO Design Research and Development Coordination Centre, which facilitates collaboration on materials and component development for DEMO. Additionally, it operates the Remote Experimentation Centre, enabling scientists to engage in fusion experiments remotely from its control room in Japan. Both initiatives have contributed to strengthening European fusion energy expertise.[73] In tandem with IFERC, European supercomputing resources developed under EuroHPC-JU initiative is another competitive advantage for the European fusion energy industry. The construction of a 47-petaflop supercomputer at Cineca in Italy, which will be developed through a €50 million agreement between ENEA, EUROfusion, and Cineca, is being specifically designed and allocated for fusion energy research to support plasma physics simulations and advanced materials analysis.[74]

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66 Barabaschi, P., Kamada, Y., & Shirai, H. (2019). Progress of the JT-60SA project. *Nuclear Fusion, 59*(11), 112005. https://doi.org/10.1088/1741-4326/ab03f6

67 Barabaschi, P., Kamada, Y., & Shirai, H. (2019). Progress of the JT-60SA project. *Nuclear Fusion, 59*(11), 112005. https://doi.org/10.1088/1741-4326/ab03f6

68 Moore, J. (2024, July 3). *Breaking ground at IFMIF-Dones.* ITER. https://www.iter.org/node/20687/breaking-ground-ifmif-dones

69 Wirth, B., Paz-Soldan, C., Albert, F., Babineau, D., Bell, K., Collins, C., … & White, A. (2024). *Report of the FESAC Facilities Construction Projects Subcommittee.* USDOE Office of Science (SC)(United States).

70 Bachmann, C., Siccinio, M., Acampora, E., Aiello, G., Bajari, J., Boscary, J., … & Zammuto, I. (2025). Engineering concept of the VNS-a beam-driven tokamak for component testing. *Fusion Engineering and Design*, 114796.

71 Dzitko, H., Barabaschi, P., Cara, P., Carin, Y., Lorenzo, S. C., Davis, S., … & Yagi, M. (2024). Overview of Broader Approach activities. *Fusion Engineering and Design, 201,* 114259.

72 Vries, G. de. (2024, September 6). *Ploughing through clouds of electrons.* EUROfusion. https://euro-fusion.org/eurofusion-news/ploughing-through-clouds-of-electrons/.

73 Dzitko, H., Barabaschi, P., Cara, P., Carin, Y., Lorenzo, S. C., Davis, S., … & Yagi, M. (2024). Overview of Broader Approach activities. *Fusion Engineering and Design, 201,* 114259.

74 Vries, G. de. (2023, June 27). *Enea, eurofusion and Cineca signed agreement to develop a new 50 million Euro supercomputing service in Italy.* EUROfusion. https://euro-fusion.org/member-news/agreement-50-million-euro-supercomputing-service/.

Additionally, cloud-based HPC solutions are expanding access to computational power, enabling European fusion energy companies to leverage both dedicated supercomputing infrastructure and cloud computing platforms to accelerate commercialisation.[75]

There are many more fusion facilities throughout Europe that support European competitiveness in fusion energy. ASDEX, TCV, WEST, SMART, and MAST-U are all medium-size tokamaks which contribute unique experimental insights to the European research ecosystem. Linear devices Magnum PSI, PSI-2, and JULE-PSI enable testing for plasma-wall interactions and plasma-facing materials.[76] A number of universities have smaller devices which also contribute to the overall fusion research ecosystem, bolstering the European fusion energy ecosystem's overall competitiveness.

Europe is also home to world-class laser infrastructures that serve as essential platforms for laser-plasma interaction experiments, target design testing, and the refinement of scientific codes for inertial fusion energy. Key facilities to study inertial fusion energy include the Laser Mégajoule (LMJ), LULI2000, and Apollon lasers in France; ELI Beamlines in the Czech Republic; ELI-NP in Romania; and the PHELIX facility at GSI Darmstadt in Germany.

The timelines required for the construction and subsequent operation and maintenance of such fusion testbeds and programmes depend on consistent public sector funding. In this regard, Europe has provided relatively stable and sustained support for fusion energy research over several decade, enabling the development of world-class R&D infrastructure. This has allowed the EU to largely avoid "mothballing", in which devices under construction are never completed or put into operation due to sudden funding cuts. Mothballing has been more common in the United States, where alternating political cycles of increased support followed by periods of cuts have made consistent long-range public sector fusion energy strategies and testbed construction difficult.[77,78,79] Europe, by maintaining steadier funding, has largely avoided this disruption in fusion energy development.

Existing Private Fusion Energy Startups

Europe's existing fusion energy companies are fundamental to building a competitive commercial industry. Although there is still space in the fusion energy industry for new players to emerge, as evidenced by the announcement of Pacific Fusion in late 2024 in the United States,[80] there is an expectation within the fusion energy investment community that "winnowing" will occur as companies emerge as "winners" by hitting key demonstration milestones and attracting further investments.

The fusion energy market has many of the characteristics which typically prevent market fragmentation, as it has high R&D intensity, economies of scale, and the need for strategic public-private cooperation.[81] This typically results in a few dominant companies emerging. In some of these types of industries, such as aerospace, pharmaceuticals, and energy, strong governmental support through research, technology, and education policies has resulted in the emergence of "pan-European champions", with companies like Airbus accruing massive market capitalisations and driving overall productivity growth in the economy.[82]

Therefore, although European policy should promote new fusion energy companies siting themselves in Europe, the mantle of Europe's commercial fusion energy industry may well be carried by the fusion energy startups which exist today. Whether the European fusion energy ecosystem can incubate them to emerge as industry giants may be determinative in whether fusion energy can increase overall European competitiveness.

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75 Clean Air Task Force, EPRI, & Fusion Advisory Services. (2024). *A Survey of Artificial Intelligence and High Performance Computing Applications to Fusion Commercialisation.* Clean Air Task Force.

76 *Eurofusion devices.* EUROfusion. (2024, June 28). https://euro-fusion.org/devices/

77 Bromberg, J. L. (1985). *Fusion: Science, politics, and the invention of a new energy source.* MIT Press.

78 McCray, W. P. (2010). 'Globalization with hardware': ITER's fusion of technology, policy, and politics. *History and Technology, 26*(4), 283-312.

79 Dean, S. O. (2013). *Search for the ultimate energy source a history of the U.S. Fusion Energy Programme.* Springer New York.

80 *What's different about Pacific Fusion's pulsed magnetic concept?* ANS. (2024). https://www.ans.org/news/article-6523/whats-different-about-pacific-fusions-pulsed-magnetic-concept/.

81 Mosconi, F. (2009). The Rise of «European Champions» in the Single Market A First Assessment. *Economic Integration in the EU Enlarged: From Free Trade Towards Monetary Union,* 81-118.

82 Mosconi, F. (2009). The Rise of «European Champions» in the Single Market A First Assessment. *Economic Integration in the EU Enlarged: From Free Trade Towards Monetary Union,* 81-118.

Indeed, many of Europe's leading fusion energy companies, though sometimes less well capitalised than some of their U.S. counterparts, are built on a sound theoretical foundation and are credible paths to commercial fusion power.

Proxima Fusion, a direct spinout from the Max Planck Institute for Plasma Physics Wendelstein 7-X device, exemplifies how Europe's R&D ecosystem is supporting commercial fusion energy development. Proxima is developing a Quasi-Isodynamic (QI) stellarator designed to eliminate current-driven instabilities found in other fusion energy concepts.[83] The company aims to achieve net-energy gain by 2031 with its *Proxima Alpha* prototype and deliver a commercial power plant, named Stellaris, by the late 2030s.[84] Proxima's innovative approach to artificial intelligence was featured in CATF's recent report on the intersection of fusion energy and AI, as the company's "Starfinder" tool will enable Proxima to rapidly explore the "Pareto frontier" of different viable stellarator design, finding optimal balances of performance and manufacturing complexity.[85] Reflecting this AI prowess, Proxima recently secured a grant from the German Federal Ministry of Education and Research (BMBF) to advance stellarator design using AI.[86]

Focused Energy, a direct spinout of the Technical University of Darmstadt, is developing direct drive inertial fusion energy (IFE). The company includes key members of the team that achieved energy breakeven at the National Ignition Facility, bringing unparalleled expertise in laser fusion energy techniques.[87] Featured in CATF's report on fusion energy and AI, Focused Energy integrates AI-driven "cognitive simulation" with experimental progress to optimise design decisions, refine predictive models, and minimise costly trial-and-error iterations. In addition to advancing its fusion energy concept, the company is pioneering target pellet manufacturing to make laser fusion energy fuel economically viable. Focused Energy has also announced a Memorandum of Understanding with the government of the state of Hesse in Germany to develop a 1 GW power plant by 2035.[88]

Renaissance Fusion, founded in 2020 and headquartered in Fontaine, France, is developing a stellarator-based fusion energy machine that integrates high-temperature superconductors (HTS) with thick flowing liquid metal walls for improved efficiency and sustainability. The company has successfully validated its liquid metal wall technology in a cylindrical loop, a key step towards developing its plasma-facing components. Renaissance Fusion plans to launch their demonstrator device in late 2026, with a 1 GW stellarator power plant targeted for the early 2030s.[89,90]

Marvel Fusion, founded in 2019 and headquartered in Munich, Germany, is developing a laser-driven inertial fusion energy (IFE) approach using ultrafast, high-contrast lasers to irradiate nanostructured fusion targets. Marvel is pursuing a proton-boron (pB11) fuel cycle to enable direct energy conversion from charged alpha particles. The company is advancing its experimental capabilities through a $150 million laser facility at Colorado State University, upgrades to the ELI-NP laser system in Romania, and collaboration with the German Federal Agency for Disruptive Innovation to validate its physics concepts. Marvel Fusion is aiming to achieve "proof of technology" at the Colorado facility in 2027.[91]

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83 *How the most advanced stellarator in the world set the stage for commercial fusion.* Proxima Fusion. (2025). https://www.proximafusion.com/press-news/how-the-most-advanced-stellarator-in-the-world-set-the-stage-for-commercial-fusion

84 Proxima Fusion. (2025). https://www.proximafusion.com/

85 Clean Air Task Force, EPRI, & Fusion Advisory Services. (2024). *A Survey of Artificial Intelligence and High Performance Computing Applications to Fusion Commercialisation.* Clean Air Task Force.

86 Proxima Fusion awarded €6.5M from BMBF to partner with the University of Bonn, Forschungszentrum Jülich, and the Technical University of Munich on AI for Fusion Engineering. (2024). https://www.proximafusion.com/press-news/proxima-fusion-awarded-grant-from-bmbf-to-partner-with-the-university-of-bonn-forschungszentrum-julich-and-the-technical-university-of-munich-on-ai-for-fusion-engineering

87 *Laser fusion.* Focused. (2025). https://www.focused-energy.co/.

88 Energynews. (2025, March 17). *Laser Fusion Power Plant project at the Biblis site in Germany.* energynews. https://energynews.pro/en/laser-fusion-power-plant-project-at-the-biblis-site-in-germany/.

89 *Company.* Renaissance Fusion. (2025). https://renfusion.eu/company

90 Fusion Industry Association. The global fusion industry report 2024. Washington, DC: Fusion Industry Association; 2024

91 *The Ultimate Clean Energy Solution.* Marvel Fusion. (2025). https://marvelfusion.com/.

Gauss Fusion, founded in 2022 as a venture between industrial partners with extensive experience in procurement and construction for ITER and other European research institutions, aims to develop a gigawatt-scale stellarator power plant by the early 2040's. Gauss Fusion has secured competitive public grants, including funding from the German Federal Ministry of Education and Research (BMBF) to advance key enabling technologies, such as demountable coils and fuel cycle technology. Gauss Fusion's approach emphasizes modularity, simplified maintenance, and component-level innovation to reduce complexity for economical fusion energy devices. By bridging state-led research and private-sector execution, Gauss aims to accelerate fusion energy's path to commercialisation and industrial scale.

Novatron Fusion, based in Sweden, is developing a stable axisymmetric mirror machine designed for cost-effective operation using copper electromagnets, with the potential to later incorporate HTS magnets into future devices. The company achieved first plasma on its Novatron 1 experimental device in January 2025, successfully integrating key subsystems. Novatron is also leading The TauEB project, backed by the EIC Pathfinder Programme, which aims to enhance plasma confinement time by over 100 times through a combination of magnetic confinement, ambipolar plugging, and ponderomotive confinement using RF fields. The company's long-term goal is to develop a 1.5 GWe power plant, N4, by the end of the 2030s.[92]

Deutelio, based in Switzerland, is developing a "PoloMac" magnetic fusion energy concept relying on poloidal magnetic confinement. Spun out of research done by University of Padua Professor and company founder Filippo Elio, the PoloMac aims to use "magnetic tunnels", or clearances in the magnetic field, to allow access to in-vessel dipole coils for support, feeding, and cooling.[93,94]

Firefly Fusion, a Franco-Swiss startup spun out of EPFL, is developing a compact tokamak machine designed around a negative triangularity plasma configuration aimed at to improve stability and confinement. The company is developing an experimental device, called *Luciole*, which aims to use actively cooled copper magnets and conventional materials to accelerate development timelines and reduce costs,[95] and eventually plans to incorporate High-Temperature Superconductors into a later machine.[96]

GenF, founded in 2024 in France, is developing a laser-driven inertial confinement fusion energy machine in partnership with CNRS and CEA. A recipient of France 2030 programme support, GenF aims to commercialize its machine by 2040 and connect to the grid by 2050, targeting 1 GW power output. The company draws on an industrial base of high-tech suppliers including Thales, Framatome, and Assystem.Its development plan will proceed in three phases: an initial phase through 2027 focused on modeling and simulation calibrated by experiments at facilities like the Laser Mégajoule (LMJ); a second phase from 2027 to 2035 dedicated to maturing key technologies such as multiple laser synchronization, cryogenic target production, and new first wall materials; and a third phase beginning in 2035 leading to the construction of a first prototype.[97,98]

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92 *Technology.* Novatron Fusion. (2025). https://www.novatronfusion.com/technology

93 Elio, F., Elio, F., Leone, M., Fulceri, T., & Sborchia, C. (2024). Technical Report: The Polomac approach to fusion energy. *The Journal of Technological and Space Plasmas,* 172-180.

94 *Deutelio.* (2025). https://www.deutelio.com/.

95 Facility, D.-D. N. F. (2025, April 22). *#fusionenergy #negativetriangularity #burningplasma #plasmaphysics…: DIII-D national fusion facility.* #fusionenergy #negativetriangularity #burningplasma #plasmaphysics… | DIII-D National Fusion Facility. https://www.linkedin.com/posts/d3dfusion_fusionenergy-negativetriangularity-burningplasma-activity-7320515238141771776-e8Ae/.

96 Fusion energy base. (2025). https://www.fusionenergybase.com/organisations/firefly-fusion

97 *The promise of Fusion & Genf.* GenF. (2025, May 13). http://www.genf-systems.com/.

98 *Thales inaugurates Genf, a first step towards nuclear fusion energy.* Thales Group. (2025, May 15). https://www.thalesgroup.com/en/worldwide/group/press_release/thales-inaugurates-genf-first-step-towards-nuclear-fusion-energy

The presence of industry trade groups to organize these private sector voices, both from startups and industrial actors, also allows the needs of the private sector to be advocated for in a unified, technology-agnostic manner to be incorporated into European fusion energy strategies. This has the potential to increase the competitiveness of the European private fusion energy industry.[99,100]

Prior to the construction of demonstration and pilot plant machines, it is difficult to say with confidence which companies' concepts will translate into commercial success. However, they represent "shots on goal" for the European fusion energy ecosystem to achieve commercial fusion power. While some of these companies may be smaller than some of their U.S. or Chinese counterparts, their success is central to Europe's ability to build a globally competitive fusion energy industry. Europe's position in the international fusion energy landscape will ultimately depend on how effectively its ecosystem supports these startups in scaling and achieving commercial viability.

Fusion Energy Talent and Education

Europe's fusion energy education system is another key competitive advantage for Europe. Universities are considered "uniquely powerful incubators for fusion venture creation," according to a recent study authored by Dennis Whyte, former director of MIT's Plasma and Fusion Science Center.[101] Indeed, a majority of fusion energy companies which exist today "originated" out of a university lab.[102] Universities are "vertical integrators", uniquely capable of holding and understanding the entirety of the fusion power plant concept.[103]
According to the study, as the fusion energy industry commercialises, universities will play an increasingly crucial role by providing cost-effective, shared research capabilities, drawing on expertise from adjacent high-tech fields, and maintaining openness in research that avoids national security restrictions at national labs.[104]
As nonprofits, they avoid many competitive conflicts, making them ideal hosts for shared facilities while training the next generation of fusion scientists and engineers. Their low barriers to cross-institutional collaboration and natural role as hubs for young talent have the potential to further drive fusion energy venture creation.[105]

Europe's universities are well-positioned to support European fusion energy commercialisation. Flagship fusion programmes exist at institutions such as École Polytechnique Fédérale de Lausanne, Institut Polytechnique de Paris, the Max Planck Institute for Plasma Physics, Eindhoven University of Technology, Paris Sorbonne University, Bordeaux University, the Max Planck Institute for Plasma Physics, Eindhoven University of Technology, University of Seville,and Aix-Marseille University, amongst others.[106] Additionally, the Erasmus Mundus Joint Master Degree (EMJMD) FUSION-EP offers a high-level, research-focused education in magnetic fusion energy, coordinated across eight partner universities in Belgium, the Czech Republic, France, Germany, and Spain. This programme equips students with interdisciplinary expertise critical to fusion energy development.[107] Europe's broader R&D infrastructure further strengthens fusion energy workforce development by providing internships and postdoctoral opportunities

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99 *Fusion driven by industry.* European Fusion Association. (n.d.). https://www.europeanfusionassociation.eu/.

100 Anderson, C. (2025, March 28). *FIA calls for targeted support for fusion startups in the EU startup and SCALEUP strategy.* Fusion Industry Association. https://www.fusionindustryassociation.org/fia-calls-for-targeted-support-for-fusion-startups-in-the-eu-startup-and-scaleup-strategy/.

101 Whyte, D. G., Paz-Soldan, C., & Wirth, B. (2023). The academic research ecosystem required to support the development of fusion energy. *Physics of Plasmas, 30*(9).

102 Whyte, D. G., Paz-Soldan, C., & Wirth, B. (2023). The academic research ecosystem required to support the development of fusion energy. *Physics of Plasmas, 30*(9).

103 Whyte, D. G., Paz-Soldan, C., & Wirth, B. (2023). The academic research ecosystem required to support the development of fusion energy. *Physics of Plasmas, 30*(9).

104 Whyte, D. G., Paz-Soldan, C., & Wirth, B. (2023). The academic research ecosystem required to support the development of fusion energy. *Physics of Plasmas, 30*(9).

105 Whyte, D. G., Paz-Soldan, C., & Wirth, B. (2023). The academic research ecosystem required to support the development of fusion energy. *Physics of Plasmas, 30*(9).

106 Fasoli, A., Becoulet, A., Belonohy, E., & Vecchio, A. (2023). (publication). *The 2023 HUMAN RESOURCES (HR) SURVEY FOR THE EUROPEAN FUSION RESEARCH PROGRAMME.* EUROfusion.

107 Van Oost, G., Beyer, P., Devitre, A., Guirlet, R., Noterdaeme, J. M., & Thienpondt, H. (2021). The European master of science in nuclear fusion and engineering physics (FUSION-EP): 15 years of experience. *European Journal of Physics, 42*(2), 024002.

that help students transition into professional roles. Furthermore, young fusion professionals have opportunities to pursue independent research in fusion energy through Bernard Bigot Researcher Grants, or more broadly, through European Research Council Starter Grants.[108,109] Notably, ITER hosts a robust internship programme, offering hands-on experience in fusion research and technology development.[110]

FuseNet, the EUROfusion-led coordinating body for European fusion energy education, serves as the nexus for workforce development through education. The organisation attracts and trains the scientists, engineers, and technicians needed for a future commercial fusion energy industry. FuseNet organises outreach activities, including an annual teacher's day, fusion teaching materials in multiple languages, and events for Master's and PhD students.[111] It also funds summer and winter schools, along with six-month internships across Europe, ITER, and other global fusion research sites. It is therefore a competitive advantage for the European fusion energy ecosystem, serving as a lever for European policymakers to shape workforce development for the competences which will eventually be needed for Europe's fusion energy startups to be globally competitive. In particular, desired skill sets will likely somewhat shift from plasma physics to engineering as plans for commercial power plants take shape. FuseNet has shown promising results over the last decade. The number of fusion physicists and engineers has grown by approximately 15% between 2015 and 2023, and the number of professionals with necessary "acquired skills" has grown in nearly every area of the fusion plant life cycle, from design to decommissioning.[112] The recently launched "Skills4Fusion" program aims to complement this effort by addressing skills gaps in both fission and fusion energy.[113]

The most recent assessment of the European fusion education system does identify areas which need to be improved in fusion education.114 Technically, competencies in plasma engineering and operations, as well as diagnostics, require strengthening across the continent.115 Now that JET is no longer active and ITER is not yet operational, it is particularly important that the "tacit knowledge" developed on these machines is transferred through effective education programmes to a younger generation of professionals, as currently directed in the EUROfusion knowledge management strategy.[116] However, while these are clear action areas, Europe's fusion education system remains a significant competitive advantage for the European fusion energy industry's competitiveness.

Fusion for Energy (F4E) Joint Undertaking

The Fusion for Energy (F4E) Joint Undertaking is a unique asset for the European fusion energy ecosystem, providing a structured mechanism for supply chain coordination. F4E was originally established in 2007 as the Domestic Agency responsible for managing Europe's contribution to the ITER project, Broader Approach Activities, and preparations for the construction of a demonstration fusion energy machine. In 2012, F4E's mandate was broadened to include a stronger industrial focus, to expand Europe's fusion energy industrial base for the long-term development of fusion energy and to ensure competitive European participation in the future global fusion energy market. It also included a mandate to support innovation and competitiveness in fusion energy technologies as part of advancing Europe's broader Innovation Union agenda on the international stage.[117]

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108 Tischler, K. (2024b, March 18). *Eurofusion researcher grant applications open.* EUROfusion. https://euro-fusion.org/eurofusion-news/erg25open/.

109 ERC grant schemes. European Research Council. (2025). https://erc.europa.eu/sites/default/files/2022-09/ERC%20grant%20schemes.pdf

110 Admin. (2025, April 3). *Internships.* ITER. https://www.iter.org/public/jobs/internships

111 *The European Fusion Education Network.* FuseNet. (2025). https://fusenet.eu/.

112 Fasoli, A., Becoulet, A., Belonohy, E., & Vecchio, A. (2023). (publication). The 2023 *HUMAN RESOURCES (HR) SURVEY FOR THE EUROPEAN FUSION RESEARCH PROGRAMME.* EUROfusion.

113 *Go4fusion and Skills4Nuclear: Boosting fusion energy research and nuclear skills by 2028.* Research and innovation. (2025, March 6). https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/go4fusion-and-skills4nuclear-boosting-fusion-energy-research-and-nuclear-skills-2028-2025-03-06_en

114 Fasoli, A., Becoulet, A., Belonohy, E., & Vecchio, A. (2023). (publication). *The 2023 HUMAN RESOURCES (HR) SURVEY FOR THE EUROPEAN FUSION RESEARCH PROGRAMME.* EUROfusion.

115 Fasoli, A., Becoulet, A., Belonohy, E., & Vecchio, A. (2023). (publication). *The 2023 HUMAN RESOURCES (HR) SURVEY FOR THE EUROPEAN FUSION RESEARCH PROGRAMME.* EUROfusion.

116 Belanohy, E. (2023). (rep.). *EUROfusion Knowledge Management Strategy.* EUROfusion.

117 Fusion for Energy. (2025). *Capabilities of F4E.* Fusion for Energy.

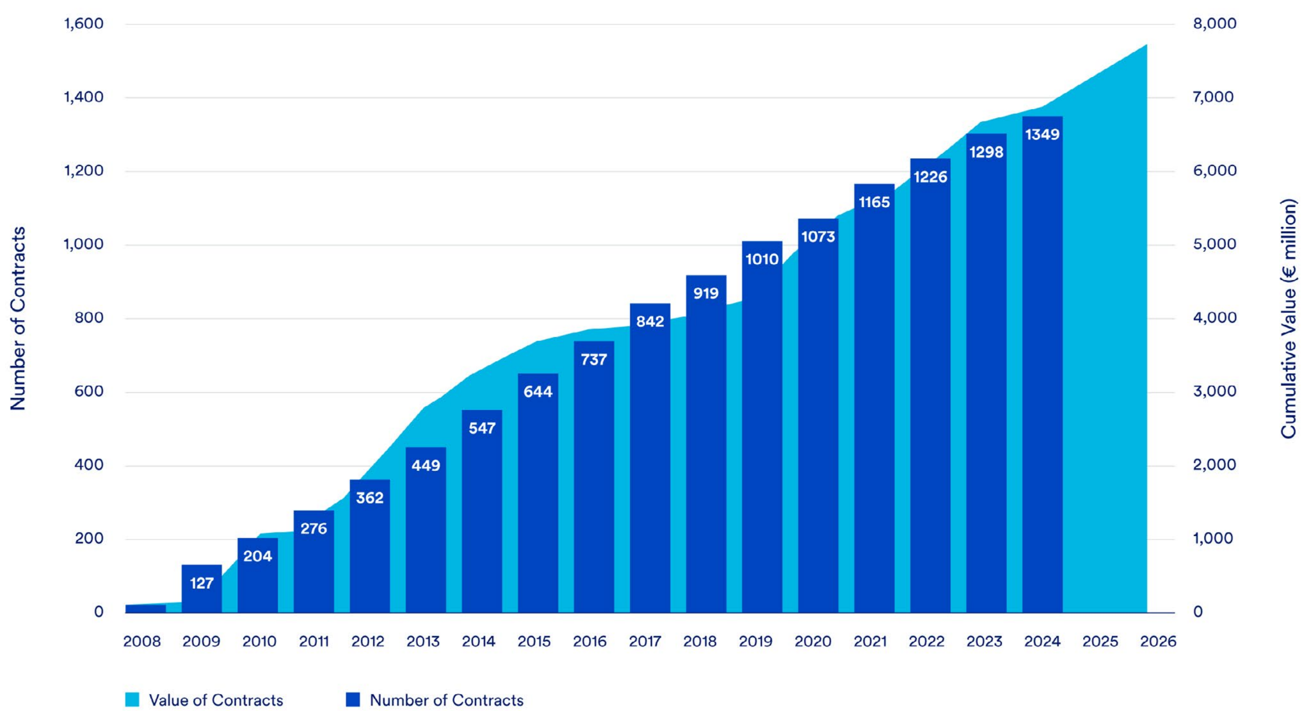
While all ITER members are required to have Domestic Agencies (DAs) to oversee national contributions to the project, F4E is unique in scale with a more sophisticated procurement structure than its counterparts due to Europe's increased responsibilities as the project host. Over the course of its existence, F4E has managed over 1300 procurement contracts with industry totalling more than €7 billion in value. During this time, F4E has built expertise in managing complex procurement processes, developing strong industry relationships, and cultivating technical know-how in manufacturing. The organisation has also developed an in-house engineering capacity to increase the TRL levels of fusion energy systems. In doing so, it has linked the fusion energy community with the broader European industrial sector, creating a world-class supply chain for fusion energy components.

Prior to the widespread rise of private fusion energy companies, this supply chain existed almost wholly to serve ITER and Broader Approach activities. However, as fusion energy moves toward commercialisation, this supply chain will support the component manufacturing required for commercial fusion energy companies around the world. Unlike many emerging industries that must build and coordinate supply chain infrastructure from the ground up, Europe already benefits from F4E's established capacity to engage and coordinate with fusion energy component suppliers. This positions F4E to help scale up supply chain activities beyond the levels developed for ITER, and strategically orient them to directly support the demands of commercial fusion energy deployment. As the Draghi Report highlights, protecting and promoting strategic supply chains in industries capable of contributing to the pillars for growth is essential—and F4E is already equipped to deliver on that goal.

Specifically, the Industrial Liaison Officers (ILO) Network within F4E serves as a key connector between F4E and industry, with one liaison officer per Member State who facilitates information sharing, raises awareness about upcoming calls, and provides impartial guidance on technical, contractual, and financial matters.[118]

Figure 2: Number and Value of Contracts Placed by F4E Since 2008

Credit: F4E



118 European Commission: Directorate-General for Energy, *Foresight study on the worldwide developments in advancing fusion energy, including the small scale private initiatives.* Publications Office of the European Union; 2023. Available from: doi/10.2833/967945

As fusion energy moves toward commercialisation, the ILO Network could serve as a bridge between industrial players and fusion energy R&D to support partnerships. F4E has taken steps to deepen its connections with industry through its recent "Call for Expressions of Interest" for private sector entities to collaborate with F4E.[119] It is also piloting PPP projects as part of its Technology Development Programme.[120]

Fusion for Energy's recent interim report was a mixture of successes and areas for improvement.[121] F4E's handling of BA procurement received high marks, which some reviewers argued demonstrates F4E's capabilities to manage projects effectively. However, F4E was criticised for chronic underachievement of milestones for the ITER project, which were largely attributed to unrealistic ITER project baselines adopted in 2016 and in-kind requirements of the ITER project for ITER delays.[122] This suggests the cause of delays is not necessarily inherent to F4E. The review also suggested a need to recruit individuals with diverse and adequate skill sets to modernise staff ability to adjust to a changing ecosystem. These challenges must be addressed for F4E to be harnessed as a driver for competitiveness of the EU fusion energy industry, but the review indicates that the core capabilities are present for F4E to take on a larger role.[123]

Weaknesses

Overlapping and Competing Governance Structure

A fundamental weakness of the European fusion energy sector is its overlapping and competing governance structure, which leads to unclear goals and authority and prevents harnessing the full potential of the European strong R&D ecosystem as a competitive advantage for a commercial fusion energy industry. Successful fusion energy commercialisation in the near term will require effective coordination in policy implementation between government, laboratories and universities, and private fusion energy startups. To this point, private sector actors have not had defined mechanisms to be true partners in European fusion energy decision making. A comprehensive, unified vision aligning stakeholder efforts is essential to build the experimental campaigns and technology development programmes critical to commercialisation. To compete with highly coordinated, state-sponsored efforts like those in China, Europe must address inefficiencies and break down information silos.

Europe's current challenges in governance and alignment stand in contrast to its early success in coordinating fusion energy development across the Union. In 1999, Europe established the European Fusion Development Agreement (EFDA) to unify fusion energy research efforts, coordinating technical activities across research institutions and industry, managing JET experimental campaigns, and allocated funding to fusion energy research centres though lump-sum grants with limited

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118 European Commission: Directorate-General for Energy, *Foresight study on the worldwide developments in advancing fusion energy, including the small scale private initiatives.* Publications Office of the European Union; 2023. Available from: doi/10.2833/967945

119 Barcelo, J. (2024, November 15). *F4E call for expression of interest boosts collaboration with private fusion enterprises.* Fusion for Energy. https://fusionforenergy.europa.eu/news/f4e-call-for-expression-of-interest-boosts-collaboration-with-private-fusion-enterprises/.

120 *Barcelo, J. (2025b, April 7). F4E launches two pilots of the Technology Development Programme.* Fusion for Energy. https://fusionforenergy.europa.eu/news/fusion-technology-development-research/.

121 European Commission: Directorate-General for Energy, Pancotti, C., Catalano, G., Colnot, L., Banfi, S. et al., *Interim evaluation study of the implementation of the Council decision (Euratom) 2021/281 amending decision 2007/198/Euratom establishing the European joint undertaking for ITER and the development of fusion energy and conferring advantages upon it – Final report,* Publications Office of the European Union, 2025, https://data.europa.eu/doi/10.2833/1515037

122 European Commission: Directorate-General for Energy, Pancotti, C., Catalano, G., Colnot, L., Banfi, S. et al., *Interim evaluation study of the implementation of the Council decision (Euratom) 2021/281 amending decision 2007/198/Euratom establishing the European joint undertaking for ITER and the development of fusion energy and conferring advantages upon it – Final report,* Publications Office of the European Union, 2025, https://data.europa.eu/doi/10.2833/1515037

123 European Commission: Directorate-General for Energy, Pancotti, C., Catalano, G., Colnot, L., Banfi, S. et al., *Interim evaluation study of the implementation of the Council decision (Euratom) 2021/281 amending decision 2007/198/Euratom establishing the European joint undertaking for ITER and the development of fusion energy and conferring advantages upon it – Final report,* Publications Office of the European Union, 2025, https://data.europa.eu/doi/10.2833/1515037

flexibility.[124,125] According to the Council of Europe, EFDA was successful in creating "a single and fully integrated fusion research programme".[126]

However, there is no longer a single coordinating agency for fusion energy development in Europe. The Fusion for Energy (F4E) Joint Undertaking (JU), as explained previously, was established in 2007.[127] On the other hand, EUROfusion was established in 2014 to coordinate EU fusion energy research initiatives under the European Fusion Roadmap, aligning R&D funding strictly with roadmap priorities. As a consortium, representatives from its member research institutions allot this funding according to the "share" of the individual centres in the overall work plan, as determined by EUROfusion representatives.128 As EUROfusion describes it in their European Fusion Roadmap, put simply, F4E is primarily engaged in building and manufacturing, whereas EUROfusion is dedicated to scientific research and experimentation within the European fusion energy community.[129]

The rationale for creating F4E and EUROfusion as separate entities, at the time of their respective inceptions, was perfectly reasonable. EFDA, under its original framework and funding allocation, lacked the capacity to manage the large-scale industrial effort required to supply ITER, and the ITER agreement mandated the establishment of a domestic agency to oversee Europe's contributions. F4E's establishment intended to allow EFDA to focus on its scientific work without taking on industrial responsibilities beyond its capacity.

On the other hand, funding under EFDA was inefficiently distributed, leading to the creation of EUROfusion in 2014 as a decentralised, neutral consortium where scientific priorities—not political influence—would guide research funding decisions and thus experimental priorities. Under this model, funding allocations were determined through a structured decision-making process driven by scientists, ensuring that resources were directed toward the most pressing technical challenges of ITER and DEMO. The intent was that F4E's focus on industry coordination and component procurement, combined with EUROfusion's focus on R&D, would accelerate both efforts.[130,131]

However, with the benefit of hindsight, this framework has created a governance structure ill-suited for developing and supporting the modern European fusion energy industry with the presence private fusion energy developers. With its focus strictly on a roadmap that prioritises ITER, followed by a European public sector DEMO project, followed by a handoff to commercial industry, EUROfusion channels Europe's strong R&D ecosystem toward the predetermined "winner" of the DEMO design. This prevents a technology-neutral approach to enable competition on an even playing field between concepts, in order to allow approaches to emerge based on technical and commercial merit.

The decentralised structure of funding distribution between the consortium members of EUROfusion, while originally intended to ensure neutrality, instead excludes private fusion energy startups, giving them no seat at the table to actively influence experimental or enabling

124 Admin. (2013, November 20). *Fusion electricity production in practical terms.* ITER. https://www.iter.org/node/20687/fusion-electricity-production-practical-terms

125 *The EFDA ROADMAP: Fusion electricity to the European grid by 2050!.* FuseNet. (2013). https://fusenet.eu/efda-roadmap-fusion-electricity-european-grid-2050

126 COUNCIL DECISION (2007/198/Euratom) establishing the European Joint Undertaking for ITER and the Development of Fusion Energy and conferring advantages upon it

127 COUNCIL DECISION (2007/198/Euratom) establishing the European Joint Undertaking for ITER and the Development of Fusion Energy and conferring advantages upon it

128 EUbusiness, & eub2. (2014, October 8). *Eurofusion – the European Fusion Joint Programme – Eubusiness.com: EU News, business and politics.* EUbusiness.com | EU news, business and politics. https://www.eubusiness.com/energy/eurofusion/

129 Donné AJ. The European roadmap towards fusion electricity. Philosophical Transactions of the Royal Society A. 2019 Mar 25;377(2141):20170432.

130 Admin. (2013, November 20). *Fusion electricity production in practical terms.* ITER. https://www.iter.org/node/20687/fusion-electricity-production-practical-term

131 *The EFDA ROADMAP: Fusion electricity to the European grid by 2050!.* FuseNet. (2013). https://fusenet.eu/efda-roadmap-fusion-electricity-european-grid-2050

technology research prioritisation according to what would most help them commercialise their designs to put fusion energy on the European grid. Instead, the DEMO design has sole priority. Such anti-competitive policies are precisely what the Draghi report warns against to avoid stifling growth.[132]

Furthermore, as a consortium without independent legal status, EUROfusion in its current form cannot establish public-private partnerships, preventing direct collaboration with industry.[133] As a result, the public and private sectors often work separately on the same challenges, resulting in duplicative efforts and slowing overall progress. This has only recently emerged as an issue; when fusion energy was primarily a public-sector effort, procurement infrastructure was sufficient for linkages to industry. However, as the fusion energy landscape evolves to include multiple public and private stakeholders, EUROfusion's structural limitations hinder the ability to align efforts under a unified vision and drive coordinated progress.[134]

At the same time, EUROfusion's mandate limits F4E's ability to coordinate or implement fusion energy policy, despite being better structurally suited to do so. As a Joint European Undertaking, F4E has the mechanisms to establish public-private partnerships, but any programme similar to the U.S. INFUSE or the Milestone-Based Fusion Development Programme would encroach on EUROfusion's role by allocating funding and determining R&D priorities.[135] The institutional separation is further compounded by the fact that only DG Research participates in the EUROfusion General Assembly, while only DG Energy sits on the F4E Governing Board, despite both entities operating under the Euratom framework.

There is a recognition amongst the two organisations that greater coordination is required for a cohesive European fusion energy mission, evidenced by their recent Memorandum of Understanding establishing a new framework for collaboration to align the two organisation's efforts towards their "common vision".[136]

The Fusion Energy Group also recommended the establishment of a European Fusion Coordination Committee to create a clearly defined central authority. However, introducing an additional body could exacerbate existing fragmentation rather than resolve it. A singular public-sector entity with the authority to coordinate directly with the private sector is essential to enable a coherent and effective fusion energy commercialisation strategy.

EUROFusion Roadmap Not Adapted To Private Sector Timeline

The timeline of the EUROFusion roadmap is another key weakness in Europe's ability to compete in the global fusion race. While private fusion energy companies plan to deploy pilot plants within the next decade, EUROfusion is instead as an entity following an outdated schedule that fails to align with the industry's rapid advancements.[137] This has the effect of preventing the European fusion energy ecosystem from adjusting research priorities and integrating recent scientific and technological progress to accelerate fusion energy commercialisation.

EUROfusion's current roadmap follows a sequential "handoff" approach of ITER, to DEMO, to commercial deployment. DEMO, a publicly funded project originally envisioned as the first grid-connected fusion energy machine, was conceived at a time when commercial fusion energy was considered a distant goal. The idea was that DEMO would serve as a foundational platform for future private-sector innovation. However, this vision predates recent advancements in enabling technologies and plasma physics, which have fueled the global rise of private fusion energy startups.

The first phase, through 2030, focuses on completing ITER construction and the conceptual design of a public-sector European DEMO pilot plant; a second phase, from 2030-2040, centring on ITER's burning plasma experiments and DEMO's engineering design; and a third phase, after 2040, dedicated to optimising plasma and advancing DEMO's construction, with DEMO

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132 Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations.* European Commission.

133 EUROfusion itself does not possess independent legal status. Instead, it operates under the legal umbrella of the Max Planck Society.

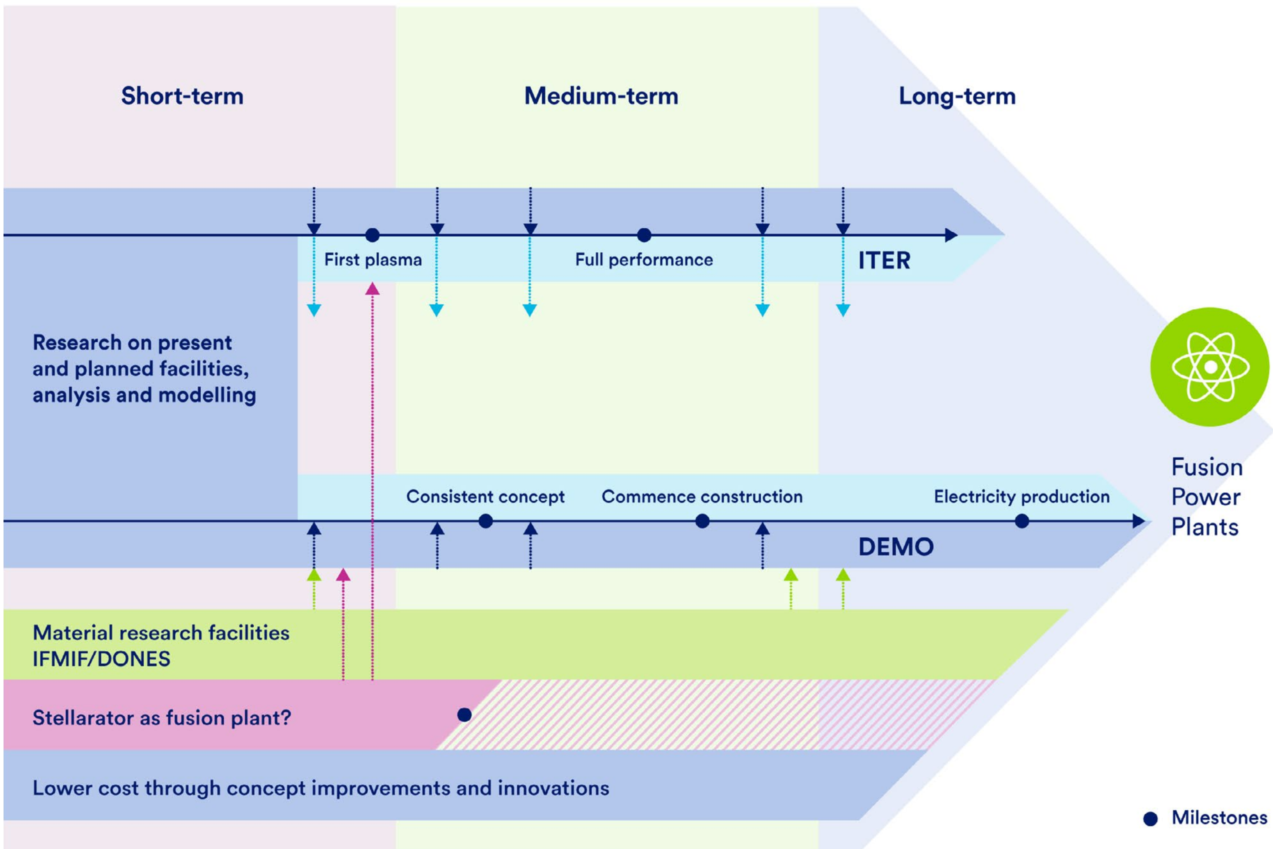
134 *Legal notice.* EUROfusion. (2025, March 25). https://euro-fusion.org/legal-notice/.

135 COUNCIL DECISION (2007/198/Euratom) establishing the European Joint Undertaking for ITER and the Development of Fusion Energy and conferring advantages upon it

136 Barcelo, J. (2025, February 18). *F4E and eurofusion reinforce collaboration.* Fusion for Energy. https://fusionforenergy.europa.eu/news/f4e-eurofusion-collaboration-memorandum-of-understanding/

137 Donné AJ. The European roadmap towards fusion electricity. Philosophical Transactions of the Royal Society A. 2019 Mar 25;377(2141):20170432.

Figure 3: Visualisation of Current EUROfusion Roadmap[138]



reaching the grid between 2045-2050.[139]
Each stage is designed to be interdependent; for example, DEMO's design requires solutions for tritium breeding and exhaust, which are (somewhat)[140] dependent on ITER's outcomes. In parallel with DEMO construction, the roadmap calls for "a science, technology, innovation and industry basis to allow the transition from the demonstration fusion plant to affordable devices suitable for large scale commercial deployment" *following* DEMO operations.[141]

138 Donné AJ. The European roadmap towards fusion electricity. Philosophical Transactions of the Royal Society A. 2019 Mar 25;377(2141):20170432.

139 Donné AJ. The European roadmap towards fusion electricity. Philosophical Transactions of the Royal Society A. 2019 Mar 25;377(2141):20170432.

140 The original roadmap assigned ITER sole responsibility for developing tritium breeding and exhaust management systems. However, due to ITER delays, other efforts have emerged in parallel. The UK's LIBRTI programme is advancing tritium breeding research, while some private companies are working on tritium management systems and several fusion energy firms are developing in-house solutions.

141 Donné AJ. The European roadmap towards fusion electricity. Philosophical Transactions of the Royal Society A. 2019 Mar 25;377(2141):20170432.

However, the commercial sector is not waiting for DEMO development. Private industry believes that multiple fusion energy companies could achieve net energy gain before 2030, and that pilot plants connected to the grid will likely occur before 2035.[142] Indeed, with Commonwealth Fusion Systems' recent siting agreement for its ARC power plant, there is a concrete plan to connect a pilot plant to the grid in the United States in the early 2030s. European private fusion energy companies are also operating on more aggressive timelines than the public sector. For example, Focused Energy has signed an MOU with the state of Hesse to launch a 1 GW laser-based power plant by 2035 in Germany.[143] Meanwhile, delays at ITER have pushed first plasma to 2036 and DT operations to at least 2039, timelines which private sector efforts are likely to surpass. This makes the envisioned handoff from ITER to DEMO to the private sector both unlikely and uncompetitive as a commercialisation pathway.[144]

Europe could not have foreseen the global rise of the private fusion energy sector when the original roadmap was published in 2018. Indeed, the fact that Europe's strategy is obsolete reflects the newfound feasibility of near-term fusion energy development; just seven years after publication of the EUROfusion roadmap, **global fusion energy commercialisation is well ahead of schedule**.

Around the world, countries have adjusted their government fusion energy strategies to adapt to this new reality. Public-private partnerships to support the private sector and coordinate action have popped up in the U.S., the U.K., and even within EU Member States such as Germany.[145] The US has also launched the Office of Fusion Energy Sciences Building Bridges initiative, adapting research priorities in collaboration with private sector needs, and its long-term fusion energy development plan focuses on a concept-agnostic research and development plan, solving critical enabling technologies gaps that are widely required across the sector such as materials development, tritium breeding, and internal fusion machine components.[146,147] On the other hand, China's state-sponsored programme appears to regularly adjust its technical programme to match industry progress. Germany has also embarked on its Fusion 2040 strategy, and its new government has made clear they intend to compete in the global race for fusion energy, with the goal of building the first commercial fusion energy machine in Germany.[148]

However, bureaucratic lethargy has prevented similar adaptations at the EU level. With funding allocations largely based on a timeline that is no longer viable, the EU's strong R&D ecosystem is not being effectively utilised to close the scientific and technology gaps for fusion energy startups to get on the grid as soon as possible. Until European fusion energy policy is built around the fundamental goal of supporting private sector fusion energy startups reach the European grid as soon as possible, and orients its resources to support such commercially relevant R&D, its fusion energy development policy cannot support a competitive industry. **The longer Europe delays fundamentally rethinking this timeline, the further it will fall behind.** Typically, clean energy innovation follows a "path-dependent" pattern, where progress builds cumulatively, allowing early adopters to develop "lead markets" which develop a comparative advantage in the sector.[149,150]

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142 Fusion Industry Association. The global fusion industry report 2024. Washington, DC: Fusion Industry Association; 2024

143 Tischler, K. (2025). *Focused Energy signs MoU to build Germany's first fusion power plant at Biblis site.* Fusion Energy Insights.

144 European Commission: Directorate-General for Energy, *Foresight study on the worldwide developments in advancing fusion energy, including the small scale private initiatives.* Publications Office of the European Union; 2023. Available from: doi/10.2833/967945

145 European Commission: Directorate-General for Energy, Smith M, Gérard F, Bene C, Shankar S, Finesso A, Moynihan M et al. *Analysis on a strategic public-private partnership approach to foster innovation in fusion energy: final report.* Publications Office of the European Union; 2024. Available from: doi/10.2833/323326

146 Allain, J. (2025). FES Building Bridges Vision. https://www.energy.gov/sites/default/files/2024-12/fes-building-bridges-vision_0.pdf

147 Anderson, C. (2025, March 25). *U.S. launches Fusion Energy Strategy 2024.* Fusion Industry Association. https://www.fusionindustryassociation.org/us-launches-fusion-energy-strategy-2024/

148 Anderson, C. (2025, March 25). *Germany announces New Fusion Funding Programme.* Fusion Industry Association. https://www.fusionindustryassociation.org/german-government-announces-new-fusion-funding-programme/

149 Mazzucato M. The green entrepreneurial state. The politics of green transformations. 2015 Jan 9;28:9781315747378-.

150 Jänicke, M., & Jacob, K. (2004). Lead markets for environmental innovations: a new role for the nation state. *Global environmental politics, 4*(1), 29-46.

Inaction today will therefore hamper the ability of fusion energy companies to emerge as drivers of high-growth innovation to support European competitiveness.[151]

There is a recognition amongst many EU decision makers that this timeline is no longer effective or realistic. *"There are colleagues from the private sector who talk about timetables which are much more aggressive than those we have in ITER... they're talking about commercial deployment much earlier; it's a ten-year difference in what we're talking about,"* Massimo Garriba, the European Commission's Deputy Director-General responsible for the coordination of Euratom policies explained. *"This is potentially the benefit of the ecosystem and the possibility of having disruptive technology from the private sector."*[152] We expect the revised fusion energy strategy to be released by the European Commission to address this discrepancy, and we urge a bold rethink to adopt a timeframe on par with the rest of the global fusion energy ecosystem.

Lack of Regulatory Certainty

For fusion energy to commercialise rapidly, "fit-for-purpose" regulatory frameworks which reflect the operational profile of fusion energy must be adapted or developed. In particular, fusion energy regulations should not fall under frameworks developed for nuclear fission installations. Fusion energy has significantly different hazards than fission energy (including no risk of meltdown and production of shorter-lived, lower-level waste than fission power plants). Thus, strict regulatory frameworks designed for fission plants are inappropriate for fusion energy machines. Use of fission regulations for fusion energy would create unnecessary barriers to commercialisation and scale-up.

Fusion energy companies need regulatory certainty to attract venture funding as well as to secure contracts with EPC firms for site construction. Establishment of technologically neutral, goal-setting, and proportional regulations allow for adequate flexibility in design and evolution of near-term and long-term fusion energy machines which may have different design and operational requirements. Such regulatory frameworks enable fusion energy companies to confidently begin building fusion power plants. Given the long lead times for building fusion power plants, companies targeting commercialisation in the 2030s need clarity in the near term to be able to assure partners that regulatory requirements will not become a roadblock.

In response, governments around the world are taking actions to enable fit-for-purpose regulatory frameworks to support fusion energy industry development and provide regulatory certainty. The United Kingdom amended its Energy Act in 2023 to exclude fusion energy machines from the radiological licensing process that fission energy power plants need to follow. The year prior, the UK government decided that fusion energy installations would be regulated under their Health and Safety Executive and their Environment Agency instead of their Office for Nuclear Regulation, following a similar pathway that was previously used for JET.[153] Similarly, in 2023, the U.S. Nuclear Regulatory Commission (NRC) decided to regulate fusion energy machines within their "byproduct materials" framework developed for particle accelerators and industrial uses of radioactive material, rather than their fission framework. In August of 2024, the ADVANCE Act codified the NRC's decision within the Atomic Energy Act, adding a definition of fusion energy machine within the existing definition of byproduct material.[154] The NRC is now working on a rulemaking process and on regulatory guidance with the goal to finalize its regulatory process for fusion energy by 2027. In March 2025, Japan released an initial white paper announcing a new "graded-approach" fusion energy device regulation system based under their radioisotope framework, rather than their fission-based one.[155]

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151 Mazzucato M. The green entrepreneurial state. The politics of green transformations. 2015 Jan 9;28:9781315747378-.

152 Keating, D. (2024, October 28). *Can Europe get fired up to compete globally on nuclear fusion?*. Euractiv. https://www.euractiv.com/section/eet/news/can-europe-get-fired-up-to-compete-globally-on-nuclear-fusion/.

153 Anderson C. "Biggest Piece of Energy Legislation in the UK's History" Will Support UK's Fusion Development. Fusion Industry Association. 2023. Available from: https://www.fusionindustryassociation.org/biggest-piece-of-energy-legislation-in-the-uks-history-will-support-uks-fusion-development/.

154 Holland A. NRC decision separates Fusion Energy Regulation from nuclear fission; 2023. Available from: https://www.fusionindustryassociation.org/nrc-decision-separates-fusion-energy-regulation-from-nuclear-fission/.

155 Holland, A. (2025, March 25). FIA responds to Japan's Cabinet Office on the "Basic Approach to ensuring safety for realization of fusion energy" Draft paper. Fusion Industry Association. https://www.fusionindustryassociation.org/fia-responds-to-japans-cabinet-office-on-the-basic-approach-to-ensuring-safety-for-realization-of-fusion-energy-draft-paper/.

The initial steps of separating fusion energy from fission regulation and creating a preliminary radiological licensing framework has helped assure investors and commercial partners that fusion energy companies will not face overly burdensome regulations which could hinder scale-up. This clarity helps create a supportive business environment for private fusion energy companies. This is what companies look for as they decide where to build their sites, and European countries must therefore offer similar certainty to international competitors. Ultimately, radiological regulation in the European Union is a member state responsibility. Currently, Germany is leading the way among EU member states to establish domestic, fit-for-purpose regulations for fusion energy separate than fission. This is a positive development for fusion energy deployment in Europe, and it would be beneficial for other member states to follow Germany's lead. However, there is an urgent need at the European level to align regulatory principles for fusion energy companies operating across the continent.[156]

The EU has acknowledged the need for greater regulatory certainty in fusion energy, which it intends to address in its updated fusion energy strategy.[157] This aligns with the broader strategy of the Competitiveness Compass, which states that avoiding regulatory burden through "proportionate, stable, coherent and technology neutral" regulations are essential for the competitiveness of key European sectors.[158] As Heike Freund, COO of Marvel Fusion, based in Munich, explained, "It's difficult for startups to scale when there's no consistent regulatory framework across Europe."[159]

While no two member states are likely to adopt identical frameworks, the absence of general alignment with at least a clear directive to separate fusion energy from fission could hinder the emergence of pan-European fusion energy champions capable of driving productivity growth. The Draghi Report warns that this type of regulatory misalignment tends to lead to limited economies of scale, a reduction of the availability of large capital pools for breakthrough innovations, and adds unnecessary complexity and bureaucracy for businesses.[160] Fusion energy companies in Europe are at a severe disadvantage as compared to their international partners in early growth stages if they are confined to comparatively smaller, domestic markets as compared to competitors operating in U.S. or Chinese markets. If pan-European champions are unable to emerge at scale, fusion energy will be blocked from fulfilling its potential to increase energy security, drive effective decarbonisation, and drive productivity growth. The lack of certainty surrounding fit-for-purpose regulatory certainty is therefore a clear weakness of the European fusion energy ecosystem.

Lower Levels of Private Sector Investment in Fusion Energy Startups

European companies have largely missed out on the private sector fusion energy investment boom, with only two fusion energy companies sited in Europe thus far exceeding $100 million in funding.[161] Only a small portion of investments in fusion energy startups have gone to European companies.[162] Part of this issue is attributable to Europe's capital markets. The Draghi report notes that "European capital markets are undersupplied with long-term capital" as compared to other advanced economies. As a result, EU markets remain overly dependent on bank financing, which, as the Draghi Report notes, are "ill-equipped to finance innovative companies." Banks often lack the expertise to evaluate and monitor these firms and have difficulty assessing their largely intangible assets as collateral.

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[156] GRS, KIT, & European Commission Directorate-General for Energy. Study on the Applicability of the Regulatory Framework for Nuclear Facilities to Fusion Facilities: Towards a specific regulatory framework for fusion facilities; 2021.

[157] Righi, E. (2025). *The state and prospects of Fusion Energy Workshop – Event.* IEA. https://www.iea.org/events/the-state-and-prospects-of-fusion-energy-workshop

[158] European Commission. (2025, January 29). *A competitiveness compass for the EU* (COM(2025) 30 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52025DC0030

[159] Anderson, C. (2025d, April 16). *Germany's new government readies for a push towards fusion power.* Fusion Industry Association. https://www.fusionindustryassociation.org/germanys-new-government-readies-for-a-push-towards-fusion-power/.

[160] Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations.* European Commission.

[161] Keating D. UK and US advance promising nuclear fusion research, the "Holy Grail" of energy. www.euractiv.com. EURACTIV; 2024. Available from: https://www.euractiv.com/section/eet/news/uk-and-us-advance-promising-nuclear-fusion-research-the-holy-grail-of-energy/.

[162] Anderson, C. (2025, March 25). *European Parliament hosts first-of-a-kind fusion public hearing.* Fusion Industry Association. https://www.fusionindustryassociation.org/european-parliament-hosts-first-of-a-kind-fusion-public-hearing/.

This contributes to a lower overall risk appetite, making it harder for innovative companies to secure funding.[163] Moreover, risk-sharing instruments are limited in effectiveness due to lower appetites for risk even in public-sector institutions, with "implementing partners" such as the EIB focused on lower-risk investment scopes.[164] Finally, most European fusion companies are relatively young compared to industry giants in the U.S., making it somewhat natural that they have received less investment to date.

As a result of the findings of the Draghi report, the EU is implementing new instruments to attempt to overcome these obstacles. The European Commission is working towards the implementation of a Savings and Investments Union to better channel household savings towards supporting the innovation the EU economy requires to close productivity growth gaps by better integrating capital markets and the banking system.[165] The Competitiveness Compass also suggests that the mandates for risk-sharing instruments be altered to better channel money towards innovative sectors at lower Technology Readiness Levels (TRLs) where state aid is most effective.[166] However, while these instruments may benefit the fusion energy sector in the long term and should include fusion energy in their mandates if pursued, their implementation falls outside the scope of a fusion energy-specific industrial strategy.

Creating a globally competitive fusion energy industry built around innovative start-ups will therefore require **overcoming** this structural financing barrier as long as it exists. It is likely unrealistic to expect European capital markets to support the same breadth of fusion energy concepts as in the United States, where venture capital shows a greater appetite for risk and a willingness to back less-established or alternative approaches. The most effective way to address this gap is to use public funding as an anchor, particularly through targeted public-private partnerships, to drive investments towards the specific startups and suppliers required to commercialise fusion energy in the European Union.[167] These partnerships can help attract private investment and provide the patient capital needed to support startups in such an innovative sector. In doing so, the EU can narrow structural financing gaps to allow its other strengths, such as its R&D infrastructure and skilled workforce, to overcome this gap to support a competitive fusion energy sector.

To this point, Europe has not established a defined fusion energy public-private partnership (PPP) programme. For example, the EU does not at this point have an equivalent counterpart to the United States' Milestone-Based Fusion Development Programme (MBFDP) Public-Private Partnership Programme.[168] MBFDP, and other PPP programmes in the United States, have been partly responsible for the rapid growth of the private sector by crowding in private investment and directing public sector expertise towards the review of private concepts. The lack of a defined fusion energy PPP programme in Europe limits the EU's ability to accelerate deployment of private fusion energy startups, hampering the competitiveness of its ecosystem. Indeed, one of the Draghi report's fusion energy-specific recommendations is the creation of an EU fusion energy public-private partnership programme.[169] The Coordination and Support Action underway aims to facilitate a defined PPP programme for fusion energy during the 2026-2027 Euratom programme extension, but action is required sooner.[170]

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163 Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations.* European Commission.

164 Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations.* European Commission.

165 European Commission. (2025, January 29). *A competitiveness compass for the EU* (COM(2025) 30 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52025DC0030

166 Fuest C, Gros D, Mengel PL, Presidente G, Tirole JJ. EU innovation policy: How to escape the Middle Technology Trap. ifo Institute-Leibniz Institute for Economic Research at the University of Munich; 2024.

167 European Commission. (2025, January 29). *A competitiveness compass for the EU* (COM(2025) 30 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52025DC0030

168 European Commission: Directorate-General for Energy, Smith M, Gérard F, Bene C, Shankar S, Finesso A, Moynihan M et al. *Analysis on a strategic public-private partnership approach to foster innovation in fusion energy : final report.* Publications Office of the European Union; 2024. Available from: doi/10.2833/323326

169 Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations.* European Commission.

170 Righi, E. (2025). The state and prospects of Fusion Energy Workshop – Event. IEA. https://www.iea.org/events/the-state-and-prospects-of-fusion-energy-workshop

The EU does have some existing instruments which fusion energy companies are eligible to access, but they are not specific to fusion energy. However, without a defined fusion energy public-private partnership programme, these broader instruments are fusion energy companies' only recourse. In the absence of a dedicated fusion energy public-private partnership programme in Europe, companies are left to navigate a patchwork of general funding instruments not designed with fusion energy in mind, many of which counterintuitively penalise projects with low technology readiness levels (TRLs), despite the fact that it is precisely these industries which have breakthrough innovation potential.[171]

Some European fusion energy companies have found some success in accessing funding through the European Innovation Council. Novatron has received seed funding through the European Institute of Innovation and Technology Knowledge and Innovation Communities (EIT-KIC).[172] Proxima Fusion has also received funding through the Accelerator instrument.[173] Focused Energy, on the other hand, received equity investment from the European Innovation Council (EIC), and has also entered into a partnership with the German state of Hesse to develop its first power plant. Marvel Fusion has also received equity investment from the EIC.[174] The largest fusion-related public-private partnership in European history is the Divertor Tokamak Test project, developed in collaboration with the European Investment Bank. However, this initiative is a research consortium, separating it from the type of PPP model needed to support commercial fusion energy deployment for fusion energy startups.

However, these successes are more attributable to the initiative of individual private companies or research efforts. Moreover, going through these open calls puts undue administrative burden on companies in such a strategically important sector. Industry players have also noted that they face the challenge of confronting embedded nuclear thinking, where they have to repeatedly convince policymakers that fusion energy is green and safe, creating higher hurdles to overcome in their applications despite proclamations of technical neutrality. The Coordination and Support Action introduced in the Euratom Work Programme 2023-2025 plans to implement further actions through the EIC to support startups.[175] This would be a positive development if it is through a defined instrument specifically for fusion energy, with sufficient resources to close financing gaps and crowd in investment. However, until such an instrument is operational, and due to the existing issues relating to fundraising and availability of funds in the EU, the lack of a defined fusion energy PPP programme is a distinct competitive weakness of the European fusion energy ecosystem.

Knowledge Management Deficits

To fully leverage its accumulated R&D and developed fusion energy talent to support commercialisation, Europe needs a strong knowledge management infrastructure. Decades of experimental data from Europe's world-class R&D infrastructure should be the foundation of Europe's fusion energy ecosystem. This is particularly important as machine learning algorithms are increasingly utilised to accelerate fusion energy development. CATF's recent report on Fusion Energy & AI found that AI is already shortening design iteration cycles, reducing plant downtime, and improving performance through enhanced plasma control and laser accuracy. Companies that effectively integrate AI into their operations will gain a significant edge in the fusion energy sector, a process already underway for many European fusion energy firms.[176]

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171 Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations.* European Commission.

172 European Commission: Directorate-General for Energy, Smith M, Gérard F, Bene C, Shankar S, Finesso A, Moynihan M et al. *Analysis on a strategic public-private partnership approach to foster innovation in fusion energy : final report.* Publications Office of the European Union; 2024. Available from: doi/10.2833/323326

173 Proxima Fusion Awarded Accelerator Funding by European Innovation Council [Internet]. Proximafusion.com. 2024. Available from: https://www.proximafusion.com/press-news/proxima-fusion-awarded-eic-accelerator-funding-by-european-innovation-council

174 Anderer, T. (2025, April 9). *EIC fund invests over € 50 million in series B of marvel fusion.* FYB Financial Yearbook. https://www.fyb.de/en/eic-fund-invests-over-e-50-million-in-series-b-of-marvel-fusion/.

175 Righi, E. (2025). *The state and prospects of Fusion Energy Workshop – Event.* IEA. https://www.iea.org/events/the-state-and-prospects-of-fusion-energy-workshop

176 Clean Air Task Force, EPRI, & Fusion Advisory Services. (2024). *A Survey of Artificial Intelligence and High Performance Computing Applications to Fusion Commercialisation.* Clean Air Task Force.

However, Europe's lack of a cohesive data management infrastructure hinders harnessing this accumulated R&D as a competitive advantage. Best practices in data management follow a FAIR framework: Findable, Accessible, Interoperable, and Reusable.[177] While internally, many fusion research institutions have improved the FAIRness of their data management systems in recent years, the "lack of consistent definitions of physics quantities, sign conventions and data formats and the wide array of tools in use for data access as well as access and authorisation of end users" leads to data FAIRness being lost at the joint European level.[178] The study further finds that FAIRness of simulation data is an even worse state, with a lack of "consistent provenance capture and long-term data storage strategies outside of the first line analysis of experimental discharges"[179] Without standardised data-sharing frameworks, researchers often rely on ad hoc methods to exchange information, slowing the pace of innovation and preventing the fusion energy industry from fully benefiting from the collective expertise developed over decades.[180] This fragmentation ultimately weakens Europe's ability to harness its R&D legacy in fusion energy commercialisation through shared knowledge and resources.

This lack of synchronisation also limits Europe's ability to accelerate fusion energy development through AI. Machine learning models are fundamentally constrained by the availability of quality training data.[181] Without improved data harmonisation, AI's transformative potential in shortening design iteration cycles, reducing costs, and improving performance could be realized to increase European competitiveness in fusion energy.

This challenge is not unique to Europe—fusion data management is a global issue.[182] However, Europe's extensive R&D ecosystem should be a competitive advantage, providing its fusion energy companies with a strong foundation for AI-driven innovation. Weak data management limit Europe's ability to fully leveraging its own research as a competitive advantage.

These issues extend beyond data management to knowledge transfer within the European fusion energy workforce, where gaps in human resource practices mirror the broader challenges of fragmented knowledge retention. While fusion physics research is generally well captured through academic networks, engineering and operations often lack structured mechanisms for capturing and sharing developed expertise.[183] Engineering knowledge is often siloed within individual teams, with limited cross-institutional collaboration, while operational expertise, which is heavily tacit and developed through hands-on experience, remains largely undocumented.[184] The interim Euratom evaluation of F4E notes that F4E should serve as a gateway for accessing intellectual property (IP) generated by EU firms involved in ITER, but due to frameworks in which contractors predominantly retain IP ownership, a fragmented management and under reporting of intellectual assets has emerged.[185]

177 Strand P, Coster DP, Plociennik M, de Witt S, Klampanos IA, Decker J, Imbeaux F, Artaud JF, Bosak B, Cummings N, Fleury L. A FAIR based approach to data sharing in Europe. Plasma Physics and Controlled Fusion. 2022 Aug 22;64(10):104001.

178 Strand P, Coster DP, Plociennik M, de Witt S, Klampanos IA, Decker J, Imbeaux F, Artaud JF, Bosak B, Cummings N, Fleury L. A FAIR based approach to data sharing in Europe. Plasma Physics and Controlled Fusion. 2022 Aug 22;64(10):104001.

179 Strand P, Coster DP, Plociennik M, de Witt S, Klampanos IA, Decker J, Imbeaux F, Artaud JF, Bosak B, Cummings N, Fleury L. A FAIR based approach to data sharing in Europe. Plasma Physics and Controlled Fusion. 2022 Aug 22;64(10):104001.

180 Jackson, S., Khan, S., Cummings, N., Hodson, J., de Witt, S., Pamela, S., ... & MAST Team. (2024). FAIR-MAST: A fusion device data management system. *SoftwareX, 27*, 101869.

181 Clean Air Task Force, EPRI, & Fusion Advisory Services. (2024). *A Survey of Artificial Intelligence and High Performance Computing Applications to Fusion Commercialisation.* Clean Air Task Force.

182 Strand P, Coster DP, Plociennik M, de Witt S, Klampanos IA, Decker J, Imbeaux F, Artaud JF, Bosak B, Cummings N, Fleury L. A FAIR based approach to data sharing in Europe. Plasma Physics and Controlled Fusion. 2022 Aug 22;64(10):104001.

183 Belanohy, E. (2023). (rep.). *EUROfusion Knowledge Management Strategy.* EUROfusion.

184 Belanohy, E. (2023). (rep.). *EUROfusion Knowledge Management Strategy.* EUROfusion.

185 European Commission: Directorate-General for Energy, Pancotti, C., Catalano, G., Colnot, L., Banfi, S. et al., *Interim evaluation study of the implementation of the Council decision (Euratom) 2021/281 amending decision 2007/198/Euratom establishing the European joint undertaking for ITER and the development of fusion energy and conferring advantages upon it – Final report*, Publications Office of the European Union, 2025, https://data.europa.eu/doi/10.2833/1515037

The closure of JET further weakens Europe's fusion energy ecosystem, as it has long served as a natural hub for collaboration, where generations of researchers and engineers worked side by side, sharing expertise in a way no other European facility currently replicates given ITER operational delays.[186] EUROfusion's recognition of the need to preserve developed fusion research knowledge is a promising sign that action will be taken to improve knowledge retention. However, as of now, Europe risks losing critical institutional expertise as experienced personnel retire or leave the field, weakening its ability to commercialise fusion energy at a competitive pace.

Opportunities

There are several opportunities to enhance Europe's global competitiveness in commercial fusion energy. If effectively leveraged, these opportunities could position the sector as a strategic driver of growth, as outlined in the Draghi report.

European Investment Bank

The European Investment Bank (EIB) is a potential lever to strengthen European fusion energy public-private partnership programmes. As the lending arm of the European Union, the EIB is the world's largest multilateral lender and the biggest provider of climate finance, providing long-term finance for viable projects. The EIB supports EU policy objectives such as climate action, innovation, infrastructure, small and medium-sized enterprises (SMEs), and regional development, investing with a traditional bank's intention for achieving returns but raising funds on international capital markets and lending them on favourable terms to projects that further EU policy objectives.[187] For energy projects specifically, the EIB supports projects contributing to one or more of energy security, competitiveness, and the EU's decarbonisation objectives. In particular, the REPowerEU Plan uses the EIB uses to fund projects geared towards accelerating the transition from fossil fuels to clean energy.[188] This plan has a substantial budget for funding innovative technologies in energy. Specifically, they look to invest in projects that support renewable energy, energy efficiency and grid development, net-zero technologies and raw materials and workforce development. The acceleration of commercial fusion energy deployment therefore clearly aligns with EIB goals.

The EIB has supported fusion energy before in its partnership with the Italian governmental agency ENEA on the Divertor Tokamak Test (DTT). The project received a total investment of 500 million euros, with 250 million euros provided by the EIB, backed by the European Fund for Strategic Investments (EFSI) under the Juncker Plan, and the remaining funding coming from EUROfusion.[189]

However, private fusion energy companies have thus far not accessed EIB funds. The EIB typically requires at least a match of funds from sources outside the bank. The DTT project used EUROfusion funds to match EIB funds, which would not be an option for a private fusion energy company. Strengthening the European fusion energy ecosystem as a whole would enhance the ability of individual companies to attract private equity, making it easier to secure matching funds from the EIB in a PPP.[190]

Moreover, clear regulatory certainty will make fusion energy projects more attractive to the EIB. According to the EIB's Lending Criteria document, "The Bank takes a cautious approach to the sector and in addition to the normal screening criteria for large thermal power plants the Bank uses additional nuclear appraisal guidelines to address specific issues related to nuclear projects, such as safety regulations, radioactive waste management, plant decommissioning, technology aspects and promoter capabilities." Clearly separating the regulatory frameworks of fusion energy and fission energy would enable the EIB to use fit-for-purpose screening criteria for funding fusion energy projects, and therefore be harnessed as an opportunity to support a competitive European fusion energy sector.[191]

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186 Belanohy, E. (2023). (rep.). *EUROfusion Knowledge Management Strategy.* EUROfusion.

187 *Investment funds.* European Investment Bank. (2025). https://www.eib.org/en/products/equity/investment-funds/index

188 Repowereu and the EIB. (2023). https://www.eib.org/en/projects/topics/energy-natural-resources/energy/repowereu#:~:text=REPowerEU%20is%20an%20EU%20plan,goals%20of%20the%20REPowerEU%20plan.

189 ENEA – Divertor Tokamak Test Facility. (2019). https://www.eib.org/en/projects/pipelines/all/20180824

190 *Investment funds.* European Investment Bank. (2025). https://www.eib.org/en/products/equity/investment-funds/index

191 European Investment Bank. (2013). (rep.). *EIB and Energy: Delivering Growth, Security and Sustainability – EIB's Screening and Assessment Criteria for Energy Projects.* Kirchberg, Luxembourg.

An organisation like Fusion for Energy could serve as a technical partner to the EIB, supporting assessment of prospective fusion energy projects in areas in which the Bank may lack internal expertise for screening.

Fusion Export Markets

By the time the fusion energy market reaches maturity (according to industry projections),[192] the IEA expects that many of today's developing countries will be the fastest-growing energy markets, while demand stabilises in Europe as well as in the U.S. and China.[193] From an operational perspective, fusion energy may be a good fit for many of the needs of these markets. Its reliable, energy-dense, and zero-carbon profile, along with its capacity to generate process heat for industrial uses as opposed to electricity-only renewable sources, may indeed make it particularly well-suited for the needs of developing nations.[194,195] Fusion energy also offers advantages over fission energy in safety, geopolitical considerations, and exportability, making it a potentially viable option for countries without prior experience in nuclear energy.

This shift could position fusion energy companies to expand globally to access new energy markets. As previously mentioned, if fusion energy captures a substantial share of the rapidly expanding global electricity market, already valued at over $1 trillion, fusion energy's market contours could enable massive market capitalisations for fusion energy firms able to compete in these emerging markets.[196,197,198,199] Such pan-European fusion energy champions which are able to compete globally could help close productivity growth gaps between Europe and other advanced economies.[200]

In doing so, fusion energy deployment in emerging markets could enable Europe to fulfil its commitments to the Sustainable Development Goals as defined by the United Nations. Specifically, fusion energy could close global gaps in meeting SDG 7, which commits to affordable, reliable and sustainable energy access for all. With 100 to 115 million people entering the global middle class each year, sustainably meeting rising energy demand in developing countries is a fundamental challenge in securing global energy equity and staying below 1.5 degrees Celsius of warming.[201] With hundreds of millions of people still lacking energy access globally, and many more lacking access to consistent or abundant energy as the global upper class is accustomed to, Europe's fusion energy firms entering emerging markets could contribute to Europe's fulfilment of its global development commitments.

EU Climate Action Commitments

The European Union leads the world in climate action as the first major bloc to implement a comprehensive carbon pricing system. It also has enshrined a legally binding goal of net-zero greenhouse gas (GHG) emissions by 2050, with a 55% reduction by 2030.[202] These carbon pricing systems include the **Emissions Trading System (ETS)**, which regulates domestic emissions from EU-based industries through a cap-

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192 Fusion Industry Association. The Global Fusion Industry in 2024. 2024: Fusion Industry Association; 2024.

193 IEA. (2024, October 16). World Energy Outlook 2024 – Analysis – IEA. IEA. https://www.iea.org/reports/world-energy-outlook-2024

194 Carayannis, E. G., Draper, J., & Crumpton, C. D. (2021). Reviewing fusion energy to address climate change by 2050. *The Journal of Energy and Development, 47*(1/2), 1-46.

195 Griffiths, T., Pearson, R., Bluck, M., & Takeda, S. (2022). The commercialisation of fusion for the energy market: a review of socio-economic studies. *Progress in Energy, 4*(4), 042008.

196 Mosconi, F. (2009). The Rise of «European Champions» in the Single Market A First Assessment. *Economic Integration in the EU Enlarged: From Free Trade Towards Monetary Union,* 81-118.

197 MIT Energy Initiative, Whyte, D., Armstrong, R., & MIT Plasma Science and Fusion Center. (2024). *The Role of Fusion Energy in a Decarbonized Electricity System.* MIT.

198 IEA. (2024). *Growth in global electricity demand is set to accelerate in the coming years as power-hungry sectors expand – news.* IEA. https://www.iea.org/news/growth-in-global-electricity-demand-is-set-to-accelerate-in-the-coming-years-as-power-hungry-sectors-expand

199 Global Electricity Generation Market Value 2031 | statista. (2025). https://www.statista.com/statistics/1456985/electricity-generation-market-value-worldwide/.

200 Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations.* European Commission.

201 Kharas, H., Chris-Asoluka, S., Laveesh Bhandari, F. O., & Archibong, B. (2024, January 23). *"The rise of the global middle class": An interview with Homi Kharas.* Brookings. https://www.brookings.edu/articles/global-middle-class-interview/#:~:text=We%20are%20adding%20110%20to,powering%20the%20world%20economy%20forward.

202 *European Climate Law.* Climate Action. (2025). https://climate.ec.europa.eu/eu-action/european-climate-law_en

and-trade system, and the **Carbon Border Adjustment Mechanism (CBAM)**, which will be phased in in 2026 and applies similar carbon costs to imported goods.[203] The European Commission has also proposed new mechanisms to simplify and strengthen CBAM to prevent circumvention.[204] Furthermore, the EU's efforts to strengthen its Emissions Trading System (ETS) and the progressive phase-out of free allowances will confront hard-to-abate industries with an increasing carbon price.

Carbon pricing may help the EU establish itself as a lead market for fusion energy. Lead market theory suggests that early, strong support for climate-friendly innovations can create demand conditions that accelerate development and deployment.[205] By creating temporary market segmentations, low-carbon products can compete even before reaching cost parity with fossil-based alternatives. As these technologies gain a foothold, the "lead market" develops a comparative advantage in their production, enabling that region to have an export advantage in the technology as prices fall to naturally competitive levels elsewhere.[206] Indeed, the Clean Industrial Deal denotes the creation of green lead markets as a policy priority for competitiveness.[207] Studies have shown that carbon adjustment mechanisms will enable fusion energy penetration into energy markets earlier than markets which don't account for carbon pricing,[208] creating an opportunity for the EU to become a fusion energy lead market.

Beyond market factors, the EU has shown willingness to commit capital to promote clean energy deployment. A number of EU initiatives have unlocked significant amounts of capital to support innovation in decarbonisation and the deployment of low-carbon energy sources. The **RePowerEU plan**, part of the **European Green Deal**, has driven policy changes requiring renewable energy quotas, streamlining of permitting, and energy efficiency directives. Under the auspices of the planned **Competitiveness Fund**, there will be **$1 billion mobilised** to support industrial decarbonisation processes.[209] The **Innovation Fund** is also unlocking capital to support clean tech, battery manufacturing, hydrogen deployment, and other contributors to industrial decarbonisation.[210] Finally, the Strategic Technologies for Europe Platform (STEP), launched in 2024, was set up to boost investment in critical technologies in key target investment areas, including deep-tech innovation and clean and resource-efficient technologies.

In comparison, fusion energy commercialisation has not received the same level of political prioritisation, despite its operational profile matching Europe's sustainability values. In the recent "Clean Industrial Deal", fusion energy was mentioned only once—stating that a "fusion strategy will be proposed," including the creation of Public-Private Partnerships (PPPs) to accelerate commercialisation. This limited focus stands in contrast to the broader momentum behind EU decarbonisation and industrialisation efforts, which suggests that with sufficient political will, many of the proposals outlined in this report *could* be implemented. Meanwhile, while there is growing institutional acceptance that a **technology-neutral approach** towards clean energy will be necessary to meet climate goals, in practice it can be difficult for fusion energy actors to access funding due to embedded "nuclear thinking". This will need to be overcome for Europe's Climate Commitments to be an opportunity for fusion energy competitiveness.

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[203] Bocquillon, P. (2024). Climate and energy transitions in times of environmental backlash?: The EU 'Green Deal'from adoption to implementation. *JCMS-Journal of Common Market Studies.*

[204] *CBAM: New Commission proposal will simplify and strengthen.* Taxation and Customs Union. (2025, February 26). https://taxation-customs.ec.europa.eu/news/cbam-new-commission-proposal-will-simplify-and-strengthen-2025-02-26_en

[205] Jänicke, M., & Jacob, K. (2004). Lead markets for environmental innovations: a new role for the nation state. *Global environmental politics, 4*(1), 29-46.

[206] Jänicke, M., & Jacob, K. (2004). Lead markets for environmental innovations: a new role for the nation state. *Global environmental politics, 4*(1), 29-46.

[207] European Commission. (2025, February 26). *The Clean Industrial Deal: A joint roadmap for competitiveness and decarbonisation* (COM(2025) 85 final).

[208] MIT Energy Initiative, Whyte, D., Armstrong, R., & MIT Plasma Science and Fusion Center. (2024). *The Role of Fusion Energy in a Decarbonized Electricity System.* MIT.

[209] European Commission. (2025, February 26). *The Clean Industrial Deal: A joint roadmap for competitiveness and decarbonisation* (COM(2025) 85 final).

[210] European Commission. (2025, February 26). *The Clean Industrial Deal: A joint roadmap for competitiveness and decarbonisation* (COM(2025) 85 final).

Threats

There are a number of threats external to the European fusion energy community which could act to deter European competitiveness in the industry. Some of these are knock-on effects of weaknesses in European governance structures, while others are outside of Europe's control, but will be exacerbated the longer it takes for Europe to take necessary steps to solve its gaps in fusion energy policy.

Brain Drain

The competitiveness of the EU fusion energy industry is threatened by a "brain drain" to better paid private-sector opportunities abroad. Brain drain occurs when highly skilled professionals leave their home countries for better salaries or living conditions abroad, weakening the home country's ability to develop and deploy advanced technologies by depleting its human capital capable of driving innovation.[211,212]

The Draghi report notes that while Europe produces high quality talent in STEM fields, the talent pool tends to get depleted due to brain drain overseas. In particular, the excess "supply" of highly skilled scientists in Europe as compared to the "demand" for their skills in high-paying jobs in innovative sectors leads to European STEM expertise being absorbed by primarily the United States. This creates a cyclical challenge; without retaining top talent, building a competitive private fusion energy sector in Europe becomes even more difficult. This phenomenon has been a particular focus of study in AI, which has consistently found that talent exoduses undermine AI readiness.[213]

Although brain drain in the fusion energy industry has not been extensively studied, its dynamics closely resemble those observed in AI and other high-tech sectors. The European fusion energy industry exhibits several key "push" factors that are strongly linked to high-skilled emigration, including a shortage of high-paying jobs (due to less large private fusion energy companies) and high rates of secondary and tertiary education without sufficient domestic opportunities to absorb skilled labor. At the same time, the United States' fusion energy sector offers compelling "pull" factors, such as higher salaries, greater opportunities for career advancement and innovation, and the presence of established European diaspora networks in major fusion research hubs.[214] Additionally, language barriers are generally minimal for European professionals moving to the United States.

Brain drain would deprive Europe of the workforce required to grow a competitive fusion energy industry, which is currently one of the strengths of its ecosystem. Global competitors would receive the spillover benefits of the workforce development investments Europe has made to support its own fusion energy industry. Retaining human capital requires a multi-faceted policy approach, but the most effective solution is a rising tide: a growing European fusion energy sector that creates the high-quality jobs needed to keep fusion energy talent in Europe.

There are, of course, benefits to fusion energy professionals gaining expertise abroad to ultimately boost the European industry. It can create linkages between ecosystems, driving mutual value creation and enabling European companies to connect with the global fusion marketplace. However, Europe needs to ensure that this process does not become a "sticky" brain drain. Studies have shown that brain drain can be somewhat reversible if "skill prices" in the home country rise.[215] However, brain drain *tends* to be sticky; the longer professionals stay in their new country, the less likely they are to return to their country (or continent) of origin.[216] This is a clear impetus for the European fusion energy community to fill gaps to increase the competitiveness of the European fusion energy industry to ensure there are attractive opportunities for fusion energy professionals to return to. This is essential to avoid an irreversible "sticky" brain drain.

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211 Socol, A., & Iuga, I. C. (2024). Addressing brain drain and strengthening governance for advancing government readiness in artificial intelligence (AI). *Kybernetes, 53*(13), 47-71.

212 Beine, M., Docquier, F. and Rapoport, H. (2008), "„Brain drain and human capital formation in developing countries: winners and losers", The Economic Journal, Vol. 118 No. 528, pp. 631-652, doi: 10.1111/j.1468-0297.2008.02135.x

213 Socol, A., & Iuga, I. C. (2024). Addressing brain drain and strengthening governance for advancing government readiness in artificial intelligence (AI). *Kybernetes, 53*(13), 47-71.

214 Docquier, F., & Rapoport, H. (2012). Globalization, brain drain, and development. *Journal of economic literature, 50*(3), 681-730.

215 Docquier, F., & Rapoport, H. (2012). Globalization, brain drain, and development. *Journal of economic literature, 50*(3), 681-730.

216 Dustmann, C., Fadlon, I., & Weiss, Y. (2011). Return migration, human capital accumulation and the Brain Drain. *Journal of Development Economics, 95*(1), 58–67. https://doi.org/10.1016/j.jdeveco.2010.04.006

The EU has recently launched a concerted effort to *attract* top scientific talent from abroad through the "Choose Europe for Science" initiative.[217] This initiative, launched in response to funding cuts and grant cancellations in the United States tied to political debates over diversity, equity, and inclusion policies, aims to attract American researchers and foreign researchers based in the U.S. to Europe by offering a supportive environment with greater academic freedom and autonomy in conducting research. To back up the initiative, Commission President Ursula von der Leyen announced €500 million in new funding through the European Research Council (ERC) over the next three years and urged Member States to commit 3 percent of GDP to research and development by 2030. Indeed, the ERC itself can serve as a powerful tool to attract international fusion talent, as its grant funding is open to researchers of any nationality, provided they are affiliated with a European host institution. Von der Leyen also called for enshrining the freedom of scientific research into EU law.[218]

This initiative could promote the competitiveness of the European fusion energy sector. At the Choose Europe for Science event, French President Emmanuel Macron remarked, "No one could have thought that [the United States], whose economic model relies so heavily on free science, on innovation and on its ability to innovate more than Europeans and to spread that innovation more over the past three decades, would make such a mistake. But here we are."[219] If brain drain can be reversed as an opportunity rather than a threat, adding talent to the European ecosystem will increase the sector's innovative potential and therefore its potential to drive European productivity growth.

Industry Flight

A clear threat to the European fusion energy industry is the possibility of fusion energy companies leaving Europe. Thus far, the report has endogenously focused on the soundness of the European environment for global competitiveness in fusion energy, largely concentrating on factors encouraging or hindering growth potentials for existing European fusion energy companies. However, fusion energy companies can leave for other markets if they see an easier path to commercialisation beyond Europe's borders. Indeed, some fusion energy companies have already taken steps to do so, such as Marvel Fusion's move to launch a $150 million public-private partnership with Colorado State University in the United States, citing regulatory uncertainty and a lack of governmental support as a key factor in developing the project abroad.[220]

The factors which may cause fusion energy companies to decamp from Europe are not unique to the fusion energy industry. The Draghi report highlights that across innovative sectors, companies are often driven outside of the EU by overregulation, barriers to scale, and a lack of access to capital.[221] Indeed, 30% of the Unicorn companies born in Europe between the period of 2008 and 2021 ultimately moved their headquarters abroad.[222] If this trend occurs in fusion energy, Europe may struggle to benefit from the successes of its own fusion energy firms. As the Draghi report warns, company flight could prevent the EU from fully capturing the innovation spillovers generated by ventures at the forefront of breakthrough technology.[223]

However, industry movement could also be a strategic opportunity for Europe, rather than a threat. While the EU's primary focus in building an industrial strategy should focus on making its domestic fusion energy companies globally competitive, it should also seek

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217 Leali, G. (2025, May 5). *Von der Leyen, Macron knock trump's war on universities as "gigantic miscalculation."* POLITICO. https://www.politico.eu/article/eu-ursula-von-der-leyen-emmanuel-macron-choose-europe-against-us-donald-trump-war-university-gigantic-miscalculation/.

218 Leali, G. (2025, May 5). *Von der Leyen, Macron knock trump's war on universities as "gigantic miscalculation."* POLITICO. https://www.politico.eu/article/eu-ursula-von-der-leyen-emmanuel-macron-choose-europe-against-us-donald-trump-war-university-gigantic-miscalculation/.

219 Dmitracova, O. (2025, May 5). *Europe unveils $567 million push to attract researchers as French president decries us "mistake" over science policy | CNN business.* CNN. https://www.cnn.com/2025/05/05/business/europe-france-science-policy-intl

220 Amelang, S. (2023, August 8). *German start-up Marvel fusion invests in us, laments lack of support in Europe.* Clean Energy Wire. https://www.cleanenergywire.org/news/german-start-marvel-fusion-invests-us-laments-lack-support-europe

221 Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations.* European Commission.

222 Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations.* European Commission.

223 Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations.* European Commission.

to attract fusion energy activity from companies based abroad as the global commercial fusion energy market grows. Implementing the recommendations in this report as part of a broader industrial strategy would help make Europe a more attractive destination for foreign direct investment (FDI) in fusion energy.

Encouraging foreign fusion energy firms to establish their operations in Europe would allow the continent to capture growth opportunities resulting from a growing global fusion energy industry. In the near term, Europe can leverage its skilled workforce and strong R&D infrastructure to draw this activity. In the long term, regulatory certainty will be a key determinant. The primary driver of this will be the establishment of fit-for-purpose regulations at the member state level. Specifically, clearly separating fusion energy from fission energy regulations as a common European principle would signal that Europe is open for business in fusion energy. In particular, countries without substantial domestic fusion energy programmes could still become deployment markets, provided a fit-for-purpose regulatory environment is established. Europe has market factors, such as established carbon pricing and limited domestic fossil energy resources, which could make it a natural fusion energy lead market to attract FDI. However, making industry movement an opportunity rather than a threat will require the implementation of a clear industrial strategy to increase Europe's attractiveness as a fusion energy market.

Falling Too Far Behind the U.S. and China

The Draghi Report distinguishes between nascent industries where the EU can compete based on its inherent advantages, and those in which it has fallen too far behind to be competitive. While the EU's private fusion energy startup sector is currently less developed than its U.S. counterpart or the Chinese state-sponsored fusion energy programme, it is not yet so far behind that it cannot catch up. The inherent strengths of the European fusion energy ecosystem suggest that a comeback is possible, and therefore a sector worth prioritising.[224] However, if disparities continue to widen, there will be a tipping point at which the U.S. and Chinese fusion energy ecosystems pull too far ahead for Europe to be a viable competitor. This is a hallmark of clean energy innovation; countries which emerge as leaders to remain leaders by creating a comparative advantage. This creates a clear need to "act first or fast-follow" to be competitive.[225,226] If Europe misses its opportunity today, it will lose its ability for fusion energy to be a springboard to productivity growth and energy security tomorrow.

The tech sector, identified as the primary driver of the widening growth gap between the U.S., China, and the EU in the 21st century, is an illustrative example of a sector in which competition in certain areas is no longer realistic.[227] The Draghi report cites hyperscalers specifically as a sector in which Europe can no longer realistically compete for global leadership, as three U.S. companies control 65% of the European cloud market, while the largest European player holds just 2%.[228]

As long as Europe operates on a sequential timeline divorced from global commercial realities and does not adjust its R&D priorities to directly support commercialisation, it will continue to fall further behind. With the Chinese state-sponsored fusion energy programme and the U.S. fusion energy ecosystem ramping up their efforts to compete for a dominant or hegemonic position in the fusion energy industry, Europe cannot afford to let this gap continue to widen if it wants its indigenous fusion energy startups to be drivers of productivity growth. The window for European action to maintain a competitive position is still open, but it is closing rapidly unless action is taken.

224 Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations.* European Commission.

225 Mazzucato M. The green entrepreneurial state. The politics of green transformations. 2015 Jan 9;28:9781315747378-.

226 European Commission. (2025, February 26). *The Clean Industrial Deal: A joint roadmap for competitiveness and decarbonisation* (COM(2025) 85 final).

227 Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations.* European Commission.

228 Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations.* European Commission.

SECTION 4

Recommendations

Recommendation A: Shifting from a DEMO-Focused to KET-Based European Fusion Energy Strategy

As noted in the **Weaknesses** section of this report, the current EUROfusion roadmap is not integrated with global fusion energy industry realities. The sequential model of ITER construction and operation, then a public sector DEMO, then an eventual commercial industry in the second half of the century, will not enable Europe to be globally competitive. Such a "DEMO-focused" sequential model inherently crowds out competition by directing Europe's R&D resources towards the predetermined "Champion" public sector DEMO design. This strips private fusion energy companies of a key strength of the European fusion energy ecosystem, as opposed to other ecosystems in which the public sector more directly focuses their resources towards commercially relevant R&D.[229] It also diminishes the return on public investment by failing to leverage publicly funded research to maximize the competitiveness of fusion energy startups with the potential to drive productivity growth.

In the upcoming EU fusion energy strategy, the EU should move away from this sequential, DEMO-focused model towards a Key Enabling Technologies (KET)-based roadmap.[230] A KET-based model, as originally proposed in the 2023 Trinomics report to the European Commission,[231] would direct research efforts, as much as is feasible, towards commercially relevant R&D to support the competitiveness of the European fusion energy ecosystem in putting fusion energy watts on the grid. This approach complements the foundational science which needs to be carried out by the public sector to advance the frontiers of fusion research and provide a platform to support the long-term success of fusion energy deployment. Where the public sector focuses on closing enabling technologies gaps, however, these efforts must be aligned with the specific needs of industry to maximise impact. Fusion energy industry trade organisations will be essential in this process to convey a unified message about the needs of the sector writ large. As much as possible, a bottom-up approach, in which fusion energy companies articulate their needs and propose targeted solutions to be evaluated based on their impact in putting fusion energy watts on the European grid, will help ensure that the KET research priorities of the public sector are commercially relevant. In organising European fusion research efforts around KET requirements for commercialisation, the capacities of Europe's research ecosystem would be maximised in supporting the global competitiveness of the European private fusion energy industry.

Such a KET-based roadmap would, in most cases, not be a major divergence from the current DEMO-focused research activities. Major experimental areas such as tritium breeding programmes or materials testing would still be essential under either programme. It would not impact long-term foundational science programmes. However, allowing the programme to be technology-

229 European Commission: Directorate-General for Energy, Smith M, Gérard F, Bene C, Shankar S, Finesso A, Moynihan M et al. *Analysis on a strategic public-private partnership approach to foster innovation in fusion energy: final report.* Publications Office of the European Union; 2024. Available from: doi/10.2833/323326

230 Key enabling technologies, broadly speaking, are the components and systems that will be required for a functioning fusion machine. Some are common; for example, any fusion machine using a deuterium-tritium fuel mix will need a tritium breeding system for viability. Others will be more specific to certain designs.

231 European Commission: Directorate-General for Energy, Foresight study on the worldwide developments in advancing fusion energy, including the small scale private initiatives. Publications Office of the European Union; 2023. Available from: doi/10.2833/967945

neutral would allow for a research programme which does not "pick winners" ahead of time, but rather, enable companies to compete on technical merit with a common level of public sector support. A DEMO programme should not be defended as an innovation and competition-stifling "national champion".[232] Rather, new players, such as private sector startups, must be given as much as possible the same access to the built-out capabilities of the EU fusion energy R&D infrastructure that the DEMO programme is designed to have.

This approach has multiple benefits. First, such a bottom-up approach would increase flexibility in the R&D programme.233,234 Whereas a DEMO-oriented roadmap ties progress to a single design and sequential timeline, a KET-based model diffuses the risk across multiple fusion energy concepts, maximizing the likelihood of overall sector success. Secondly, this model addresses public sector concerns that the private sector is not sufficiently attuned to the enabling technologies roadblocks facing them.[235] Incorporating industry as a co-leader in determining and advocating for KET priorities would ensure that the obstacles relevant to specific private sector fusion energy approaches are fully investigated and addressed.[236]

Moving away from a DEMO-oriented roadmap should not be confused with a call to move away from DEMO as a broad concept. The DEMO programme makes valuable contributions to fusion engineering and design, and at its current design stage, is not currently a major cost. Rather, we merely advocate that private sector commercialisation plans are prioritised and their R&D needs are integrated alongside it, not subsequently or secondarily.

Recommendation B: Establish Fusion for Energy as the Sole Fusion Governance Body in Europe

Establishing Fusion for Energy (F4E) as Europe's single governance authority would resolve the current competing structures that prevent a coordinated, comprehensive, and integrated approach to European fusion energy development. The competing governance structure of the European fusion energy ecosystem cannot be resolved with mere restructuring of the two entities. Moreover, creating new entities risks adding bureaucracy without clear authority. We therefore recommend elevating F4E, an established governance body with a broad and robust mandate, to serve **as the singular European fusion energy governance entity**. This would eliminate ambiguity and resolve the current problem of overlapping and competing governance structures.

F4E's status as a **Joint Undertaking (JU) under Articles 45-51 of the Euratom Treaty** affords it vested strengths to take on this expanded role. JUs are expressly designed to connect EU research and innovation efforts with industrial development. This status also gives F4E a wide legal purview, stating, "Each Joint Enterprise shall, in each of the Member States, enjoy the most extensive legal capacity accorded to legal persons under their respective municipal law".[237] **F4E's JU status therefore provides a ready-made framework for a fusion energy governance system incorporating all facets of the fusion energy ecosystem to rapidly transition from research, to demonstration, to commercial deployment.**[238]

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[232] Donné AJ. The European roadmap towards fusion electricity. Philosophical Transactions of the Royal Society A. 2019 Mar 25;377(2141):20170432.

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

[234] European Commission: Directorate-General for Energy, *Foresight study on the worldwide developments in advancing fusion energy, including the small scale private initiatives.* Publications Office of the European Union; 2023. Available from: doi/10.2833/967945

[235] European Commission: Directorate-General for Energy, *Foresight study on the worldwide developments in advancing fusion energy, including the small scale private initiatives.* Publications Office of the European Union; 2023. Available from: doi/10.2833/967945

[236] European Commission: Directorate-General for Energy, *Foresight study on the worldwide developments in advancing fusion energy, including the small scale private initiatives.* Publications Office of the European Union; 2023. Available from: doi/10.2833/967945

[237] European Atomic Energy Community. (1957). *Treaty establishing the European Atomic Energy Community (EURATOM).* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A11957A%2FTXT

[238] *Joint undertakings.* EUR. (2025). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=legissum%3Ajoint_undertaking

Joint Undertakings have been effectively used in other industries to create a centralised structure to push green technologies towards commercialisation.[239] That F4E is already incorporated as such makes it a natural fit to assume full, unified governance responsibility for the EU's fusion energy programme. Indeed, the interim review of F4E conducted by Euratom recently stated that, due to its legal status as opposed to EUROfusion, "F4E could potentially become a central player in the EU future fusion energy landscape helping to better connect the public and private actors along the fusion energy value chain."[240]

In contrast, **EUROfusion has structural weaknesses that prevent it from accelerating fusion energy commercialisation in the near term**. Its exclusion of industry in key decisions, lack of capacity to develop a PPP framework due to its lack of independent legal status to sign contracts in its own right, and its rigid adherence to a sequential ITER-DEMO model make it increasingly obsolete. The European Commission affirmed this view in its Interim Evaluation of the 2021–2025 Euratom research and training programme: "EUROfusion has delivered well on its high-end scientific research mission… however… EUROfusion is not fit to achieve commercial exploitation of fusion power generation."[241]

In our model, the European Commission would serve in an advisory and consent role with F4E in fusion energy policy development and implementation. **Fusion for Energy would be responsible for defining a KET-based roadmap in collaboration with industry stakeholders, as well as leading its implementation.** Concretely, this would mean determining experimental priorities at unique test beds and research and knowledge centres (e.g. universities, national labs). F4E could also serve as the evaluator of bottom-up industry proposals to close KET gaps through the use of public sector test beds, assessing them based on their potential to accelerate the successful commercial deployment of fusion energy. Such a change in direction from a unidirectional procurement relationship to a partnered relationship with industry would give industry the chance to co-lead the development and implementation of European fusion energy.[242] This would require a defined, institutional role for industry within a revamped F4E.

F4E would serve as a singular body to channel and facilitate fusion energy financing to relevant bodies (though Member States would be free to concurrently run separate funds), rather than dividing funding allocation responsibilities between multiple governance organisations for distribution. With EUROfusion responsibilities absorbed under F4E, the budget that would have been split amongst F4E and EUROfusion in the next MFF should be directed solely and in full to F4E to accomplish its expanded responsibilities. Furthermore, as fusion energy moves towards commercialisation, the overall expanded requirements for fusion energy governance to drive a commercially competitive industry would require an expanded overall fusion energy budget.

F4E's workforce development responsibilities would include managing FuseNet and other educational and training programmes with a particular focus on shifting priorities to engineering and industrial competencies to prepare for commercial demonstration and pilot plant construction along the lines with a KET-based roadmap. A focus on practical retraining and upskilling pathways

239 The hydrogen industry serves as an instructive example of how F4E could be transformed into an organisation capable of governing the modern European fusion ecosystem to support global competitiveness. In 2021, the Clean Hydrogen Joint Undertaking was established to subsume the "legacy portfolio" of the previous Fuel Cells and Hydrogen Joint Undertaking as a reflection of the European Green Deal's commitment to net-zero emissions, in order to shift away from a hydrogen industry that had been mostly fossil-fuel based through hydrogen cracking. The Clean Hydrogen JU was given a clear mission that spanned the entire hydrogen value chain, from R&D to deployment. This avoided fragmented governance and enabled alignment of EU funding with long-term technology and market goals.

240 European Commission: Directorate-General for Energy, Pancotti, C., Catalano, G., Colnot, L., Banfi, S. et al., *Interim evaluation study of the implementation of the Council decision (Euratom) 2021/281 amending decision 2007/198/Euratom establishing the European joint undertaking for ITER and the development of fusion energy and conferring advantages upon it – Final report*, Publications Office of the European Union, 2025, https://data.europa.eu/doi/10.2833/1515037

241 REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Interim evaluation of the 2021-2025 Euratom research and training programme {SWD(2025) 54 final} – {SWD(2025) 55 final}

242 European Commission: Directorate-General for Energy, Pancotti, C., Catalano, G., Colnot, L., Banfi, S. et al., *Interim evaluation study of the implementation of the Council decision (Euratom) 2021/281 amending decision 2007/198/Euratom establishing the European joint undertaking for ITER and the development of fusion energy and conferring advantages upon it – Final report*, Publications Office of the European Union, 2025, https://data.europa.eu/doi/10.2833/1515037

will be required to tap into diverse skillsets across the labour force to develop the fusion energy workforce skills required to support a maturing commercial industry.

F4E would continue to govern international collaborations, such as ITER and Broader Approach Activities, but would also engage with other trusted international partners to avoid duplicative research efforts as well as to establish strategic alliances. These partnerships should be structured to accelerate scientific progress, while protecting European interests in competitiveness and intellectual property.

F4E's knowledge management programme would expand on current EUROfusion efforts, much of which F4E is already collaborating on. For data management specifically, we recommend t**he creation of an open data sharing structure for public sector fusion research broadly aligned with the Fair4Fusion blueprint**. In particular, by harmonising data ontologies through the IMAS (Integrated Modelling and Analysis Suite) data dictionary, F4E could enhance interoperability and enable comprehensive data analysis across multiple experimental and simulated results.[243] This data should be made as widely accessible as possible to fusion energy innovators, helping accelerate progress among European fusion energy companies. Doing so will ensure that decades of past and ongoing research meaningfully support commercial efforts and that Europe's strong R&D infrastructure and legacy of scientific excellence are fully leveraged. **In addition to aligning experimental data, the structure should address simulation data by creating a Long Term Simulation Storage Facility as suggested by the Fair4Fusion framework.**[244]

With increased use of in-silico modelling, it is essential that simulated findings be preserved and made accessible in a standardised format which can be compared and utilised with experimental results. From a knowledge management perspective, we recommend that F4E adopt and continue the existing EUROfusion programme, in which it is already a participating partner. In particular, a focus on ensuring tacit knowledge developed through Europe's workforce at its R&D facilities is accessible and transferable to the private sector will be key.[245]

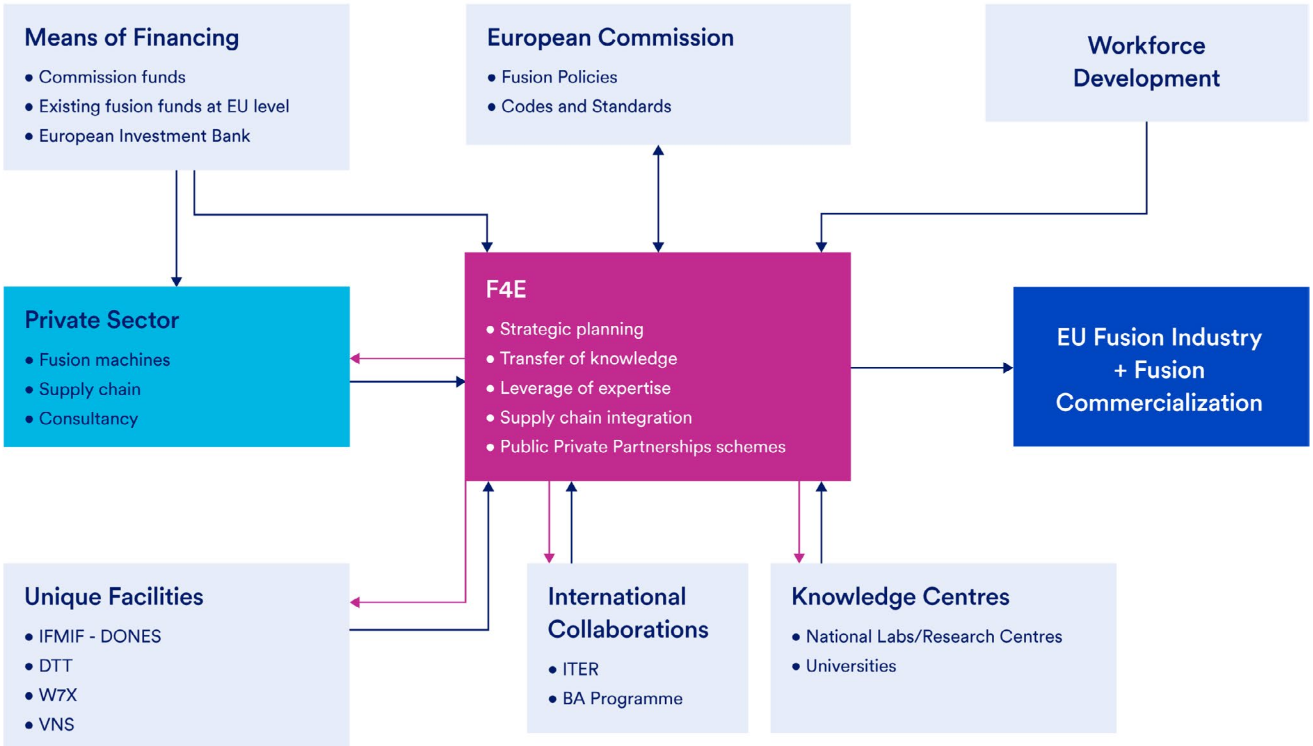
Alongside knowledge management, several other areas outlined as F4E's responsibility under our proposed strategy currently fall under EUROfusion's mandate. As a part of this reorganisation, the responsibilities of EUROfusion will need to be subsumed under F4E. **To be clear,** this would not be a merging of the two organisations. EUROfusion's structures are not suitable to accelerate the commercialisation of fusion energy. Rather, this revamped F4E would need to be enlarged, have essential EUROfusion functions integrated within a new organisational structure, and receive expanded funding to adopt these expanded responsibilities. F4E would adopt necessary policy shifts, as determined by both the European Commission and its stakeholders, both public and private, to a KET-based roadmap in these areas. This will allow an integrated roadmap reflecting the modern European fusion energy industry's needs to be established and implemented by a centralised body.

243 Strand P, Coster DP, Plociennik M, de Witt S, Klampanos IA, Decker J, Imbeaux F, Artaud JF, Bosak B, Cummings N, Fleury L. A FAIR based approach to data sharing in Europe. Plasma Physics and Controlled Fusion. 2022 Aug 22;64(10):104001.

244 Strand P, Coster DP, Plociennik M, de Witt S, Klampanos IA, Decker J, Imbeaux F, Artaud JF, Bosak B, Cummings N, Fleury L. A FAIR based approach to data sharing in Europe. Plasma Physics and Controlled Fusion. 2022 Aug 22;64(10):104001.

245 Belanohy, E. (2023). (rep.). *EUROfusion Knowledge Management Strategy.* EUROfusion.

Figure 4: New Fusion Energy Strategy Towards a Competitive Commercial Industry



Recommendation C: Retrofit Existing Public Sector Institutions' Missions to Support a KET-Based Roadmap

A KET-Based Roadmap can best be supported by **retrofitting** existing public sector fusion energy institutions and laboratories to support near-term commercialisation, as well as ensuring that any new research facilities are supporting the mission of near-term commercialisation. This retrofitting must begin with engaging with ITER, and utilising its competences to support startups pursuing fusion energy commercialisation in the near term as part of a KET-based model.

In the immediate term, ITER's primary value to private sector startups lies in knowledge transfer as well as workforce and supply chain development. The continued operation and expansion of ITER's Private Sector Fusion Engagement Programmes will be essential to maximise the value of ITER for private sector initiatives. In the long term, once operational, ITER should actively engage the private sector to explore how its experimental capabilities can address industry challenges. ITER's unique diagnostic capability can be of assistance both for answering foundational questions of plasma physics, as well as to contribute to closing KET gaps. As much as possible, we recommend that the EU utilise the facility to broadly answer remaining questions in magnetic fusion energy as a whole, rather than solely for a specific public sector DEMO design, incorporating private fusion energy startup input on ITER's utility to their plans when possible.[246]

[246] ITER, as well as Broader Approach activities, are governed jointly with partner countries. ITER in particular requires major policy shifts to be approved through the ITER council. However, Europe should use its weight to influence the organisation's direction towards the goal of a KET-based roadmap to serve the interests of the European fusion ecosystem.

Other European R&D facilities can similarly be made to support a KET-based roadmap with experimental reprioritisation to support industry. Across the European fusion energy research community, there are clear examples of where a KET-based model could better support the competitiveness of the European private fusion energy industry. The IFMIF-DONES facility, Europe's planned prototypic neutron source, should be utilised to validate materials required for private fusion energy projects as well as public fusion energy projects, as a unique resource that would provide a competitive advantage to the European ecosystem. Private industry should co-lead the determination of materials to be irradiated. Similarly, the Divertor Tokamak Test's mission to test divertor designs should incorporate the needs of industry for divertor designs relevant to their plans. One potential model could involve evaluating individual proposals for overall commercial impact, and allocating machine time at Europe's leading R&D facilities accordingly. These facilities, and others, can best support commercialisation as intended if they are allowed to serve a KET-based roadmap.

Recommendation D: Establishing an Innovation Partnership PPP Through Fusion for Energy

As part of our proposed restructuring putting F4E as the central node of European fusion energy governance, we recommend that an expanded F4E be given the mandate to immediately launch a substantive fusion energy public-private partnership programme. At the policy level, the European Commission has already recognised the need for such a partnership. Both the Draghi Report and the Clean Industrial Deal explicitly call for this.[247]

The European Commission has begun work on a public-private partnership in the form of a Co-Programmed European Partnership (CPEP). To do so, a Coordination and Support Action has been established to support the creation of an industry-led European fusion energy association (which industry has taken the lead to implement through the establishment of industry trade groups), define a suitable governance structure, develop a Strategic Research and Innovation Agenda on Fusion Energy, and lay the groundwork for a long-term European Technology and Innovation Platform, with the aim of launching the PPP during the 2026–2027 extension of the Euratom Programme.[248]

In our view, while these developments are positive steps, Europe cannot afford to wait if its startups are to be globally competitive. We therefore propose moving forward immediately with the Innovation Partnership mechanism already available to F4E.[249] These partnerships already fall under F4E's current legal mandate. Unlike standard procurement or grants, Innovation Partnerships would allow F4E to co-fund projects with industry and research actors to accelerate industrial innovation aligned with F4E's objectives and KET objectives. This would also enable industry to contribute to research closing KET gaps that otherwise would be the sole responsibility of the public sector. Moreover, F4E's scale, ILO networks, deep understanding of supply chain dynamics, and capacity to implement a KET-based roadmap within a reformed governance structure suggest that the organisation is suited to operate such a PPP.

In the near term, Innovation Partnerships could serve as a vehicle to support milestone-based development in Key Enabling Technologies. This would be particularly valuable for building necessary test stands and supporting low-TRL technologies in which commercial incentives are not yet strong enough to attract private investment, and where patient public capital can play a critical role in filling the gap. The model would foster goal-oriented progress in hitting both science and technology as well as business and commercialisation milestones.

To date, the mechanism has not been widely used. However, it is an opportunity to move ahead of the bureaucratic process of establishing a Co-Programmed European Partnership. An Innovation Partnership programme could start immediately. The development of many Key Enabling Technology systems clearly falls

247 European Commission. (2025, February 26). The Clean Industrial Deal: A joint roadmap for competitiveness and decarbonisation (COM(2025) 85 final).

248 REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Interim evaluation of the 2021-2025 Euratom research and training programme {SWD(2025) 54 final} – {SWD(2025) 55 final}

249 European Commission: Directorate-General for Energy, Smith M, Gérard F, Bene C, Shankar S, Finesso A, Moynihan M et al. *Analysis on a strategic public-private partnership approach to foster innovation in fusion energy: final report.* Publications Office of the European Union; 2024. Available from: doi/10.2833/323326

under F4E's current mandate, which includes preparing industry to support a future DEMO design,[250] (taken to mean a pilot fusion power plant designed to demonstrate the feasibility of generating net electricity from fusion energy). These include many technologies which would eventually be required for both the current DEMO-oriented roadmap and our proposed KET-based roadmap.

Council Decision (Euratom) 2021/281 of 22 February 2021 allots EUR 5 614 000 000 in current prices to the Joint Undertaking to accomplish its core objectives "to provide Euratom's contribution to the ITER international fusion energy organisation and to Broader Approach activities with Japan; and to prepare and coordinate a programme of activities for the construction of a demonstration fusion energy reactor and related facilities, including the international fusion materials irradiation facility."[251] F4E could initially finance such PPP efforts by reallocating some ITER funds, particularly during current project delays. Delays reduce immediate ITER procurement and construction costs, potentially creating short-term budget flexibility.[252] While the political sensitivities in redirecting ITER funds could emerge, these concerns are likely diminished considering the growing recognition that fusion energy commercialisation is moving faster than the sequential model allows. In the short term, repurposing ITER funds could potentially enable a programme comparable in scale to the U.S. Milestone-Based Fusion Development Programme. MBFDP received $40 million in 2024 and 2025. A repurposing of the allotted 2021-2027 funding to fund a programme of similar scope would thus represent just under 1% of funding allotted to the Joint Undertaking in the current Multiannual Financial Framework.[253] Looking ahead, keeping pace with progress abroad will require reorganising Europe's fusion energy funding landscape. As our F4E-centric model proposes, financial resources dispersed across fusion energy institutions should be channelled and distributed to relevant actors through an integrated and revamped F4E, with increased budget allocations in the next Multiannual Financial Framework to reflect fusion energy as a priority for European growth, decarbonisation, and security.

We also recommend the incentivisation of Private-Private collaboration as well where possible between fusion energy companies to move KET progress forward. A sort of R&D credit (or innovation voucher) system could be established in which fusion energy companies can contract with other private companies but "spend" the money via an R&D credit or innovation voucher.

Industry concerns do exist that bureaucratic culture within F4E could slow progress and limit flexibility, particularly if new industrial innovation efforts mirror the "heavy" procedures associated with ITER procurement.[254] However, ITER procurement involves F4E applying a specific set of requirements mandated by ITER, particularly around nuclear safety and quality assurance. These obligations, while necessary for ITER, are not inherently required for non-ITER activities. For procurement beyond ITER, the administrative burden on industry can be significantly reduced. F4E has already begun piloting a more flexible approach through its Technology Development Programme, albeit on a limited scale.[255] A shift toward a KET-based approach, supported by a streamlined structure, should address these concerns. This aligns with broader European Commission efforts to reduce bureaucratic red tape, as well as the strategic guidance outlined in the Draghi Report and the Competitiveness Compass. By adopting a more agile model and ensuring a smooth flow of expanded resources, Europe can equip its fusion energy companies and suppliers with the tools needed to compete effectively on the global stage.

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250 Fusion for Energy. (2025). *Capabilities of F4E.* Fusion for Energy.

251 *The EU's Fusion for Energy Joint Undertaking (F4E).* Access to European Law. (2025). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=legissum%3AI27070

252 European Commission: Directorate-General for Energy, Smith M, Gérard F, Bene C, Shankar S, Finesso A, Moynihan M et al. *Analysis on a strategic public-private partnership approach to foster innovation in fusion energy: final report.* Publications Office of the European Union; 2024. Available from: doi/10.2833/323326

253 The amount left unspent of that allocation is unknown externally to F4E.

254 European Commission: Directorate-General for Energy, Smith M, Gérard F, Bene C, Shankar S, Finesso A, Moynihan M et al. *Analysis on a strategic public-private partnership approach to foster innovation in fusion energy: final report.* Publications Office of the European Union; 2024. Available from: doi/10.2833/323326

255 Barcelo, J. (2025c, April 7). *F4E launches two pilots of the Technology Development Programme.* Fusion for Energy. https://fusionforenergy.europa.eu/news/fusion-technology-development-research/.

In our view, establishing Innovation Partnerships through F4E is the most immediate and effective way to support fusion energy startups through a defined public-private partnership instrument. That said, any of the proposed mechanisms—whether through the European Innovation Council, a dedicated fusion energy CPEP, or other formats—would represent positive steps for the European fusion energy sector. Indeed, with F4E at the central governance authority of the fusion energy ecosystem as our model proposes, these efforts could eventually be merged. Regardless of the model selected, we support the creation of a fusion energy PPP programme to serve as a public funding anchor to crowd in private investment, as recommended in the Competitiveness Compass.

Recommendation E: Establish PPP IP Rights Which Support Competitiveness

In establishing such a PPP programme, it will be essential to establish intellectual property standards which enable European companies in the fusion energy ecosystem to effectively commercialise the innovations developed through Innovation Partnership PPP programmes. The interim Euratom review notes that the European fusion energy ecosystem is currently at an IP disadvantage as compared to its international counterparts.[256] Much of Europe's fusion research is open access through ITER and Broader Approach activities, without adequate protections for private companies especially within PPP settings.[257]

IP rules for a PPP between F4E and industry should not be an antagonistic negotiation with both sides attempting to extract value. While F4E serves the public interest, the success of European private fusion energy companies **is itself** in the public interest as a matter of energy security, effective decarbonisation, and productivity growth. The goal of these Innovation Partnerships should not be to extract resources from the private fusion energy industry, but rather to infuse them with value to drive productivity growth. This will both increase the competitiveness of participating fusion energy developers as well as industry involved in the supply chain, both of which can contribute to European productivity growth.

IP arrangements should therefore be set up to favour industry where possible. This has been a key success of the NASA Commercial Orbital Transportation Services Programme which the United States modelled their Milestone-Based Fusion Development Programme upon.[258] Fusion for Energy's Technology Development Programme allows the industry to own the IP generated in the partnership, which could serve as a model for a larger programme. Modelling a larger PPP programme off this example would bolster the competitiveness of European fusion energy firms. This will also help innovative IP reach the marketplace for the benefit of the broader fusion energy industry, rather than remaining siloed within a government agency.

Recommendation F: Comprehensive Mapping of the European Fusion Energy Supply Chain in the Context of New Threats

The security of the European fusion energy supply chain is, as noted previously, a fundamental strength of the European fusion energy ecosystem. Through F4E's establishment as a Joint Undertaking (JU), it has created a world-class European fusion energy supply chain as a result of procurement for the ITER project, although it will need to be scaled up as the industry moves towards commercialisation. Even in the context of seemingly rising global trade barriers, the European fusion energy industry is seemingly well positioned to withstand such obstacles due to the strength of its supply chain.

Moreover, Europe is better positioned to adjust and respond to such risks because of the presence of F4E. F4E has mapped over 2300 companies and 200

[256] REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Interim evaluation of the 2021-2025 Euratom research and training programme {SWD(2025) 54 final} – {SWD(2025) 55 final}.

[257] "Euratom Scientific and Technical Committee (STC). (2023, October 20). Priorities for European nuclear research and training: An STC Opinion. [STC-2023-16 FINAL]. European Commission. [https://research-and-innovation.ec.europa.eu/document/download/8908a4d4-ad88-465f-9c9b-bbbf0e7174cc_en?filename=priorities-for%20european-nuclear-research.pdf]"

[258] European Commission: Directorate-General for Energy, Smith M, Gérard F, Bene C, Shankar S, Finesso A, Moynihan M et al. *Analysis on a strategic public-private partnership approach to foster innovation in fusion energy: final report.* Publications Office of the European Union; 2024. Available from: doi/10.2833/323326

technologies across 23 EU countries, numbers which are constantly growing. F4E's comprehensive in-house market analysis methodology and supplier assessment system allows for the identification and mitigation of supply chain weaknesses.[259] Its existing industrial liaison networks and responsibility to coordinate the supply chain for ITER, BA, and DEMO activities gives the organisation a unique insight into where kinks in the supply chain could emerge.

However, as geopolitical risks grow amid global trade realignment, we recommend that F4E formalise its internal expertise by conducting a comprehensive mapping of EU fusion energy suppliers. This mapping should identify potential overreliance on single-source suppliers, or where EU in fusion energy companies will rely on suppliers outside of the EU, in particular in regions previously considered reliable that may be less so with rising trade barriers. This would help mitigate the risk of future geopolitically based disruptions. Such an assessment should be a dynamic instrument regularly updated to reflect evolving geopolitical conditions, including the impact of newly imposed tariffs on access to critical components and materials.

There is also a risk that, as ITER procurement concludes, supply chains developed for niche fusion energy technologies without other markets could disappear in the meantime prior to the construction of DEMO or private sector pilot plants. It will be essential for F4E to understand where these risks exist and respond.

Subsequently, F4E should be empowered with a strengthened mandate to act to close the gaps or smooth kinks identified in this mapping exercise. Already, a part of F4E's mission is to develop geographically broad and sustainable supply chains. As the central node of Europe's fusion energy ecosystem, F4E could act—through the Innovation Partnership or other instruments—to incentivise private actors within Europe to fill supply chain gaps. F4E should also be empowered to build strategic stockpiles, direct investment toward resource-rich nations, and establish targeted industrial partnerships as according to the recommendations of the Draghi Report.[260]

Recommendation G: Establishing Regulatory Principles Separating Fusion Energy from Fission Energy

At the European level, a clear mandate should be established separating fusion energy regulations from regulatory frameworks developed for nuclear fission installations. This could be accomplished by amending **enabling legislation addressing radiation protection principles under Euratom**. Unlike the U.K. and the U.S., the EU will not be the direct regulatory authority issuing licenses for fusion power plants sited within EU member states.[261] As such, Member States will remain the licensing authorities for fusion power plants and will have a broad purview to establish a national fusion regulatory system. However, separating fusion energy from fission energy regulations within existing Euratom directives could sufficiently align approaches to create a relatively unified fusion energy business environment.[262]

Europe could accomplish this through modifying the Basic Safety Standards Directive, or Council Directive 2013/59/Euratom, to explicitly include fusion energy under its ionising radiation framework. Council Directive 2013/59/Euratom lays out basic safety standards for member states to meet in order to ensure protection from sources of ionising radiation. By classifying fusion energy under this directive, it would be separated from fission energy at the European level, and member states could then implement fit-for-purpose regulatory standards aligning with the Basic Safety Standards Directive. This would both align European regulations externally with the rest of the world, which is broadly regulating fusion energy machines separately from fission reactors, as well as internally, to better allow for pan-European fusion energy champions to emerge across the EU market.

259 Fusion for Energy. (2025). *Capabilities of F4E.* Fusion for Energy.

260 Draghi, M. (2024). *The future of European Competitiveness: In-depth analysis and recommendations.* European Commission.

261 Elbez-Uzan, J., Williams, L., Forbes, S., Dodaro, A., Stieglitz, R., Airila, M. I., ... & Rosanvallon, S. (2024). Recommendations for the future regulation of fusion power plants. *Nuclear Fusion, 64*(3), 037001.

262 Elbez-Uzan, J., Williams, L., Forbes, S., Dodaro, A., Stieglitz, R., Airila, M. I., ... & Rosanvallon, S. (2024). Recommendations for the future regulation of fusion power plants. *Nuclear Fusion, 64*(3), 037001.

Recommendation H: Codifying Fusion Energy as a Strategic Green Technology Across EU Legislation

The European Commission should make every effort to clarify that fusion energy is a clean energy technology aligned with the objectives of the European Green Deal and the Clean Industrial Deal. Broadly, we recommend that European policymakers consistently promote the competitiveness of the European fusion energy industry by ensuring it receives appropriate legislative support. As a baseline, fusion energy should be included in the EU's Green Taxonomy. This will clarify its eligibility for European Green Deal initiatives, including those recently laid out in the Clean Industrial Deal.[263] In our interpretation, fusion energy technologies are already eligible within the EU Green Taxonomy, but an explicit addition would help fusion energy developers and component manufacturers access funding from initiatives such as the Competitiveness Fund and Innovation Fund. These programmes are designed to accelerate exactly the kind of climate and industrial transformation that successful fusion energy commercialisation would deliver.

Another opportunity for codification to boost the fusion energy sector would be through its explicit inclusion as a net-zero technology under the **Net-Zero Industry Act (NZIA)**, which is broadly Europe's response to the U.S.' IRA. NZIA is a legislative framework to expand manufacturing capacity for key clean energy technologies needed to meet climate neutrality targets. It sets a benchmark for Europe to produce 40 percent of its annual deployment needs in net-zero technologies by 2030, capture 25 percent of the global market, and reduce barriers to scaling up production across the single market.

Including fusion energy on the NZIA's list of "strategic" technologies would open access to a broad set of industrial support mechanisms to support European private sector fusion energy competitiveness. This was originally proposed as an amendment to the NZIA, but was not adopted in the final legislation. While we understand fusion energy to be covered under the "other nuclear technologies" category, recognising it as a separate category is essential. If fusion energy were explicitly included in the NZIA, there would be no ambiguity regarding its eligibility for fast-tracked permitting procedures.[264]

Finally, there are a number of initiatives promoted as part of the Competitiveness Compass which could potentially benefit fusion energy. The European Innovation Act, if implemented, would promote the access of innovative companies to European research and technology infrastructures. The proposal of a 28th legal regime for innovative companies, simplifying administrative and regulatory burden, could also benefit fusion energy developers.[265] Proposals like these, while beyond the scope of the fusion energy sector alone, should include fusion energy in order to support the sector's contributions to innovation, decarbonisation, and energy security if implemented.

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263 European Commission. (2025, February 26). The Clean Industrial Deal: A joint roadmap for competitiveness and decarbonisation (COM(2025) 85 final).

264 Implementing the EU's net-zero industry act. (2025). https://www.europarl.europa.eu/RegData/etudes/BRIE/2025/769489/EPRS_BRI(2025)769489_EN.pdf

265 European Commission. (2025, January 29). *A competitiveness compass for the EU* (COM(2025) 30 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52025DC0030

SECTION 5

Conclusion

Europe has the tools to build a competitive fusion energy industry to close innovation gaps, leverage decarbonisation as an opportunity, and to increase security by reducing dependencies. However, the emergence of a competitive European fusion energy industry for the commercialisation of fusion energy is hampered by many of the same governance obstacles hindering European growth in the first place.

Broadly, Europe has the **in-house infrastructure and expertise** to grow a competitive fusion energy industry. Much like the Draghi report diagnoses for Europe as a whole, the challenge is not a lack of fusion energy innovation. The R&D ecosystem is driving scientific breakthroughs, a skilled workforce is already present, and the European fusion energy supply chain is world-class.

However, its soft infrastructure—overlapping governance structures, misaligned research priorities, a lack of regulatory clarity, and the absence of fusion energy public-private partnerships undermines its ability to compete globally.

The good news is that these challenges are fixable. The recommendations of this report chart a path towards closing these gaps. With such **an industrial fusion energy strategy**, Europe can leverage its existing strengths while overcoming its weaknesses to build a world-class competitive private fusion energy industry. Future technical roadmaps for fusion energy deployment should be fully aligned with this strategy.

European policymakers must urgently act to remove those obstacles to enable fusion energy close innovation gaps to drive productivity growth on the continent, utilise decarbonisation for growth, and to establish energy security. By adopting the recommendations of this report as the basis of an industrial strategy, fusion energy could reignite the European engine for growth.

ANNEX

What is fusion?

Fusion energy is released through the process of fusing lighter atomic nuclei into heavier ones, converting matter into energy as described by Einstein's equation '$E=mc^2$'. This is the same reaction that powers stars, including the Sun, requiring extreme temperatures and pressures. The rate of fusion reactions is dependent on a sufficient combination of three key factors, called the "triple product": pressure (n), temperature (T), and confinement time (τ). When these factors reach a critical threshold, known as the "Lawson Criterion," the energy produced by fusion reactions exceeds the energy required to create the necessary conditions. This would achieve **scientific breakeven**. However, **engineering breakeven**, or $Q_{eng} > 1$, is the measure of fusion's viability as an energy *resource*. It is achieved when a fusion facility delivers more power to the grid than it consumes in its operations.

Most fusion energy machine concepts fall into three main categories. **Magnetic Fusion Energy** (MFE) relies on magnetic fields to confine and control the heated plasma. The most common MFE concepts are **tokamaks and stellarators**. Tokamaks use magnetic fields to contain plasma in a toroidal-shaped chamber, and are the most well-researched fusion energy concept. Stellarators use helically twisted magnetic fields for plasma confinement without requiring a current. **Inertial Fusion Energy** (IFE) uses lasers or high-energy projectiles, called "drivers", to compress a fusion fuel target pellet rapidly enough to achieve fusion conditions. The variation in IFE concepts is typically characterised by differences in drivers and targets. **Magneto-Inertial Fusion** (MIF) combines MFE and IFE approaches, typically confining plasma using magnetic fields and subsequently compressing it with inertial mechanisms.

The majority of fusion energy concepts plan to use a Deuterium-Tritium fuel mix. DT fusion occurs at relatively lower temperatures compared to other fusion fuel concepts, at around 100 million degrees Celsius. When deuterium and tritium fuse, a spare neutron is ejected from the reaction, the kinetic energy of which is used to heat water and thereby generate electricity. Other fusion fuel concepts include Deuterium-Deuterium (DD), Deuterium-Helium-3 (DHe3), and Proton-Boron-11 (pB11). Deuterium-Deuterium (DD) fusion avoids tritium use and relies on abundant fuel but requires much higher temperatures and produces lower energy output. Deuterium-Helium-3 (DHe3) fusion is aneutronic and reduces radioactive byproducts, but helium-3 is extremely scarce and the reaction still demands high temperatures and direct energy conversion. Proton-Boron-11 (pB11) fusion also avoids neutron production and uses widely available fuels, but it faces the steepest technical barriers, with the highest temperature requirements and reliance on unproven direct conversion methods.