**Written evidence submitted by UKAEA and UKIFS (IND0009)**

*[For information about the United Kingdom Atomic Energy Authority (UKAEA) and its fusion energy research programmes, please see "additional submission" provided at the end of the response.]*

**How can UK plc capture its fair share of the economic potential of emerging or less developed energy technologies?**

UKAEA and UKIFS considers fusion to be an example of a high priority "emerging sector", which is itself comprised of "technologies". As a low carbon baseload energy technology with lower radiological hazard than traditional fission, fusion could be a strategic technology of huge importance to the world. Its commercialisation would also reinforce the UK's energy transition and long-term energy security prospects while supporting sustainable economic growth and high-skilled jobs. The UK's fusion programme aims to leverage UK research leadership into long-term industrial and commercial advantage via the growth of an internationally competitive UK fusion sector.

The UK is a genuine world-leader in the field. UKAEA, the world's largest fusion organisation, is internationally recognised for its expertise, having developed cutting-edge capabilities and operated JET[1], the world record holding magnetically confined machine which uses deuterium-tritium fuel. It is therefore realistic to target a greater than pro-rata share of this future global sector.

UKAEA owns significant IP[2] relevant to the development of fusion powerplants - a government asset - with the opportunity to apply this to adjacent sectors in the short-term and support the growth of UK companies through substantial market interest in fusion investment happening now. One example of this is joining technologies for superconducting magnets. UKAEA has developed a new technology to introduce a highly configurable, scalable, and more cost-effective process to join magnets together that is also more environmentally friendly than existing techniques. This opens opportunities for energy saving in other applications such as energy distribution, generators and high field magnetics.

The Spherical Tokamak for Energy Production (STEP) is the flagship programme in the UK's multi-strand approach to commercial leadership in fusion; by designing and building a prototype fusion energy plant, STEP will demonstrate a pathway towards the commercial viability of fusion. The forcing function of design and build of a full prototype energy plant both accelerates the shift from research to commercialisation in the technical work as well as the sourcing and development of every aspect of what will be needed in a viable fusion supply chain. The capabilities and technologies developed through STEP are widely applicable to many other approaches to commercialising fusion.

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[1] JET's final tritium experiments yield new fusion energy record - GOV.UK

[2] Determining exact ownership of the JET IP is non-trivial due to the evolution of the contractual arrangements for operating and exploiting JET over its 40-year history. Regardless of ownership, however, UKAEA believes it has a strong case for gaining access this IP subject to suitable licensing arrangements currently being discussed with the UK government and the EUROfusion consortium (whose members, including the UK, co-funded the construction and operation of JET)

UKAEA operates globally unique research facilities[3] and is investing in supply chain capability, skills development, investment opportunities, international collaborations and commercialisation activities. Across all these activities the aim is to anchor high-skilled jobs and economic growth, attract investment and build industry capability in a range of fusion systems and solutions where the UK has strengths already, to enable the UK supply chain to capture opportunities as fusion is commercialised.

**What more can the Government do to encourage greater domestic supply chain investment in the energy industry by 2035, including through the Contracts for Difference scheme?**

To encourage greater domestic supply chain investment in the fusion industry, a clear long-term commitment from the government is vital. A new fusion strategy, closely linked to the Industrial Strategy, that commands cross-party support would galvanise this nascent sector, which should make explicit political support for institutions, organisations and programmes involved in the UK's fusion energy activities.

A governmental commitment to the future introduction for fusion of a Contracts for Difference or Regulated Asset Base model would also strongly support market confidence in fusion. All such initiatives would need to be introduced at a time and in a way that makes them both credible to investors and deliverable for developers. UKAEA understands DESNZ is considering such proposals for future implementation.

**Does the UK have the supply chain capacity to deliver the required energy infrastructure by 2035, including an expanded electricity network?**

The timelines for achieving commercial fusion and thus developing required energy infrastructure are beyond those set out in the question. As fusion moves from research into commercialisation, our understanding of the required energy infrastructure and electricity network needs will increase.

The STEP programme has been established to *Deliver a UK prototype fusion energy plant, targeting 2040, and a path to commercial viability of* fusion.  The UK's leading position will be in supply (including exports) of a significant proportion of the critical systems and technologies that fusion energy requires, many of which are common to all fusion approaches.  The best means to achieve that is by bringing the experience and capacity of industry together with the deep expertise of UKIFS and UKAEA to develop capability and solutions through the practical design and delivery of a fully representative protype fusion plant. STEP will provide the first credible set of system and component orders (initially for design work, and later for product and installation) for many suppliers. The full supply chain will require capabilities at several levels, and cross-cutting services. Owing to the scale of the work and the need to secure the best innovation and best value, the supply chain will be international, but there are many areas where UK firms can lead, or where contracts with international suppliers require delivery of benefits to the UK through local jobs and facilities.

**To what extent would growing the domestic supply chain bolster UK energy security?**

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[3] Programmes - Culham Centre for Fusion Energy

UKAEA and UKIFS are actively working to expand the UK's supply chain, strengthening the country's fusion industry and enhancing its export potential for fusion technology and related innovations.

The fusion market of the future could be worth multiple £Tn’s p.a., with an estimated range of £3 - 12tn. It could be a strategic technology of huge importance. Its commercialisation would also reinforce the UK’s energy transition and long-term energy security prospects while supporting sustainable economic growth and high-skilled jobs.

The UK fusion programme responds to this opportunity, and is widely seen by global fusion research organisations, industries and fusion design companies as the most coherent and strategic in the world. This is a great achievement for the UK – especially given the ferocious global competition in technology innovation – and provides a strong foundation for moving into the next phase of delivery.

In the long term, having a strong, capable supply chain in fusion will enhance energy security for the UK as well as generating significant economic benefits. Fusion deployment via supply chain capability cannot be dependent on non-allied states.

**What are the key concerns with respect to the availability of raw materials in the supply chain and how might those be addressed?**

Fusion requires specialist and rare materials, including tritium, an isotope of hydrogen with very limited supply. UKAEA and UKIFS are working closely, alongside DESNZ to engage with other governments to meet this demand.

**Annex A.**

**Further information on fusion, the opportunity and the UK position.**

1. **Fusion**

Acceleration of large-scale clean energy provision is necessary to meet the ever-growing global energy demand and to build resilience to threats posed by climate change and challenges to energy security. This drives a global imperative to explore and progress all credible technologies that together can provide the future clean energy supply.

Fusion can be a major global source of safe, low carbon, continuous and virtually inexhaustible energy, for electricity generation and high-grade heat production. The waste produced by fusion is less radioactive and decays much more quickly than that produced in fission[4]. Fusion can enable de-carbonisation of industrial processes, helping to accelerate and sustain global net zero as demand grows, particularly in developing nations. Fusion can also power emerging energy demand from uses such as Artificial Intelligence (AI).

Fusion is the process which occurs at the centre of stars. It is the source of light and heat emitted by the Sun. When the nuclei of two light elements are 'fused', they form a heavier element and release excess energy. Fusion has the potential to provide low carbon, secure, continuous and virtually inexhaustible energy, with a lower radiological hazard to fission[5] resulting in different regulatory requirements[6]. The generation of usable energy using fusion would have six distinct advantages:

1. **Fuel abundance**: the fuels used in fusion reactions are effectively inexhaustible. Deuterium is readily extracted from seawater, and tritium is produced using lithium;
2. **Baseload power**: fusion energy does not depend on external factors such as wind or sun, making it continuously deployable at point of need;
3. **High fuel efficiency**: fusion produces more energy per gram of fuel than any other process that could be achieved on Earth;
4. **Carbon-free**: helium is the product of the fusion process – no carbon or other greenhouse gases are produced in the reaction;
5. **No chain reaction**: fusion is not based on a chain reaction. If there were any technical problems, a fusion facility could be immediately switched off and the process would stop within seconds or less;
6. **Shorter lived waste**: fusion power plants are not expected to produce the very long lived, high level radioactive waste associated with nuclear fission.

[4] Nuclear fusion breakthrough – what is it and how does it work? - BBC News
[5] Fusion Technology Report (ukaea.uk)
[6] Towards fusion energy: proposals for a regulatory framework - GOV.UK (www.gov.uk)

While fusion facilities have been in operation around the world for many decades, no facility has yet demonstrated net energy gain from fusion. The technical challenges in delivering fusion energy are considerable, in the development of the complex components and systems required and the integration of these into a complex facility that can be operated at commercially viable levels of productivity and availability. While realising net energy from a fusion reaction remains highly technologically challenging, there is emergent global consensus that fusion energy could become commercially viable[7]. The next 20 years are expected to be crucial in the transition of fusion from R&D to a commercial industry.

***So when will we see fusion energy 'on the grid' / powering industries?***

Under all technical pathways and historic precedence for market penetration, it is unlikely that fusion will make any significant contribution to global energy supply before 2050. After 2050, based on market penetration rates of large energy technologies, such as early adoption of oil and gas or conventional nuclear, fusion could reach 10% of global energy demand by 2100 – or as much as 40% if capital costs were 30% cheaper[8]. Demand for fusion energy would vary by jurisdiction. It is expected to be higher where there is emphasis on low carbon energy production, along with high population density and low availability of renewable resources and/or land[9].

2. **Why now**

**There is increasing demand for clean energy solutions.** Acceleration of large-scale clean energy provision is needed to meet growing demand and to build resilience to global climate change and challenges to energy security. This drives a global imperative to explore and progress all credible options for clean energy supply both to meet net zero commitments and in sustaining clean energy post 2050. Renewables and nuclear fission have an important role to play as part of a portfolio of solutions but alone may not provide the long-term energy security required, potentially for the UK and certainly globally[10].

**There have been advances in fusion science and technology in recent years.** Coupled with advanced manufacturing and computing capabilities now available, confidence in the 'deliverability' of fusion energy is growing[11]. The two main signifiers of this are:

- Technical "breakthroughs" achieved on JET in the UK (JET's final tritium experiments yield new fusion energy record - GOV.UK (www.gov.uk) and NIF in the USA (Lawrence Livermore National Laboratory achieves fusion ignition | Lawrence Livermore National Laboratory (llnl.gov));

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[7] https://www.imeche.org/docs/default-source/1-oscar/reports-policy-statements-and-documents/imeche-fusion-report-ao.pdf?sfvrsn=a9a29112_2. National Academies of Sciences, Engineering, and Medicine. 2021. Bringing Fusion to the U.S. Grid. Washington, DC: The National Academies Press. https://doi.org/10.17226/25991
[8] committees.parliament.uk/writtenevidence/111883/html/. See also UKAEA-STEP-PR2312.PDF
[9] The commercialisation of fusion for the energy market: a review of socio-economic studies - IOPscience
[10] Towards fusion energy 2023: the next stage of the UK's fusion energy strategy - GOV.UK (www.gov.uk)
[11] Selection include: UK's JET nuclear fusion reactor sets new world record for energy output | New Scientist, Nuclear fusion: new record brings dream of clean energy closer - BBC News, Nuclear Fusion Is Not A Moonshot But An Attainable Goal (forbes.com)

- $9bn raised by private companies focused on fusion energy concepts and technologies to date, mostly in the USA.

There is an emergent global consensus that current endeavours can transition fusion energy from R&D to commercial viability.[12],[13],[14] Fusion energy can be a pivotal part of the future global clean energy supply, providing energy security and sustaining net zero as global energy demand rises.

The UK is a world leader in fusion energy, with over 70 years' experience, including 40 years' operating the world's foremost experimental fusion plant[15]; holding the world record for energy produced by a fusion facility.[16]The UK has a unique opportunity to retain our world leading research and development (R&D) capability whilst generating long term market opportunities through the STEP programme.

The UK can secure a significant share of this market which is estimated at £3 - 12tn[17], making the UK a clean energy superpower.

**The UK has developed a global lead in the most promising fusion technologies.** This stems from its: operation of JET since 1983; building capability in the enabling technologies of fusion; and developing an approach – the spherical tokamak – that offers a promising pathway towards commercial viability. The UK's commitment to fusion and its supporting programmes – particularly the STEP programme, to build a fusion power plant in the UK by 2040 – have galvanised momentum and focus across the UK fusion sector[18], and around the world, with countries such as Germany and Japan routinely citing the UK's fusion strategy as informing their own national approaches.

**The economic opportunities associated with fusion are increasingly clear.** The gross value-added (GVA) impact of UKAEA fusion R&D activities between 2009/10 and 2023/24 was £1.8bn-£1.9bn, with UK government spend of £893m over the same period – representing a Benefit-Cost Ratio of 2. Between 2019/20 and 2022/23, an average of 5,100 jobs per year were supported in the UK economy by UKAEA activity, 60% of which were in the UK supply chain rather than working for UKAEA. The future global capital investment in the fusion market between 2050 and 2100 is estimated at £3.3tn (590 GWe installed by 2100 or 1.4% of global electricity generation in 2100), with a range of between £0.6tn to £5tn. The UK economy has so far gained more than £650 million from contracts with ITER, the international fusion mega-project under construction in France. Technologies from fusion R&D are benefitting industry in areas including robotics, materials, hydrogen, computing, and artificial intelligence.

**Other nations, multi-national alliances and private companies are responding to these developments.** In 2022, the US announced a decadal vision for commercial fusion while following

[12] https://doi.org/10.17226/25991

[13] https://www.imeche.org/docs/default-source/1-oscar/reports-policy-statements-and-documents/imeche-fusion-report-ao.pdf?sfvrsn=a9a29112_2

[14] https://www.bmbf.de/SharedDocs/Downloads/de/2024/fusion2040_programm.html

[15] JET - EUROfusion

[16] Nuclear fusion: new record brings dream of clean energy closer - BBC News

[17] DESNZ-UKAEA analysis of total capital investment in Fusion Power Plants between 2050-2100 based on UCL Energy Institute global TIMES modelling commission by UKAEA, currently unpublished. Upper bound based on Fusion following Fission's historic rollout is the footnote from the economic analysis annex

[18] Britain has a chance to be a nuclear fusion superpower. We must not blow it (telegraph.co.uk)

the UK's regulatory approach[19][20] and Japan are anticipated to publish a Fusion Strategy, similar to that published under the previous UK government, later this year[21]. China is pressing ahead with fusion development at a much-accelerated pace compared to five years ago, aiming to complete their next fusion machine (BEST, a JET scale superconducting tokamak based on ITER) by 2027.

**The private sector cannot deliver fusion by itself.** Commercial investment raised in fusion has focused on fusion developers where there are identifiable adjacent or near-term returns. The breadth and depth of fusion's challenges – combining specialist scientific expertise, manufacturing and fabrication of novel components and systems, integrated design and infrastructure construction – is beyond the capability of any single organization currently in existence. The risks and uncertainties mean that the capital, capacity and capability required is likely to be only mobilised via long-term public funding until the point at which sovereign wealth and/or energy majors – both of which may have a strategic interest in fusion delivery – price the potential reward over the risks of investment in fusion. Until then, this leaves government as the necessary convening body and funding agent to get fusion to the point of credible demonstration. The UK has in recent years:

- supported fundamental fusion science and research, mostly via UKRI;
- invested in cutting-edge R&D facilities for both academic and industry use;
- opted for a domestic programme of R&D and supply chain support as an alternative to association to Euratom (European nuclear research programme);
- pursued a tranched full-systems prototype fusion power plant programme (STEP) via a special purpose delivery vehicle (UK Industrial Fusion Solutions Ltd.), to leverage commercial funding, combine the technical capability of UKAEA with industrial capability of the UK supply chain, secure long-term value for the UK and underwrite the risks in a way that minimises exposure to the taxpayer as much as possible.

Therefore, with the potential to provide clean energy for the globe, the UK's fusion programme plays a key role in maintaining the gains that will be made from the government's commitment to decarbonise the energy system by 2030. Equally importantly, the UK's fusion programme supports a new green industrial strategy, growing the UK fusion industry and creating jobs and opportunities in the UK's industrial heartlands. It will:

- Exploit the UK's global leadership in fusion technology to support economic growth;
- Champion the UK's fusion scientists, engineers and innovators in the public and private sector, to position UK talent to lead global fusion delivery;

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[19] https://www.whitehouse.gov/ostp/news-updates/2022/03/15/fact-sheet-developing-a-bold-vision-for-commercial-fusion-energy/
[20] US Senate Passes ADVANCE Act, Including Legislation to Codify US Fusion Regulations - Fusion Industry Association
[21] Japan to draft nuclear fusion strategy amid fierce global race, Asahi Shimbun 14 September 2022; https://www.asahi.com/ajw/articles/14718757

- Leverage commercial investment into the UK fusion sector as soon as possible but without risking UK Intellectual Property and long-term strategic control.

3. **UK position**

A. ***Long-standing UK Fusion Leadership***

The UK remains at the forefront of global fusion capabilities. **UKAEA operated the European JET[22]facility between 1983 and 2023, the most powerful fusion energy machine to date.** In late 2021, JET exceeded its own world-record for fusion performance, generating 59 Megajoules of energy over a 5 second period[23]. Over 40 years, JET has been integral to building understanding in fusion science and technology, both globally and in the UK – where UKAEA has developed facilities dedicated to specific fusion technologies, such as **robotics, materials research** and **fusion fuel systems.** The UK is now decommissioning JET, which will provide further know-how to establish the viability of fusion.

The UK has also been a member of the global ITER project since its inception and has been a leading contributor to the DEMO[24] design effort. This expertise throughout the lifecycle of major fusion programmes, and across the full breadth of the current fusion delivery challenges, is unique to UKAEA and gives the UK a distinct advantage in making the leap from concept design to commercial plant.

B. ***Current UK strategy and programmes***

**The UK is currently a world leader in the development of the spherical tokamak as demonstrated in the positive results from UKAEA's MAST Upgrade[25] experiment**. The more compact form of a spherical tokamak has a number of advantages and critically is able to produce a higher power output for its size than a standard tokamak. This provides greater potential for a commercially viable machine by driving down capital cost (a key driver of the cost and competitiveness of fusion[7]) and increasing the potential for the UK to take a greater share of global fusion energy market. This forms the basis of the UK's **STEP Programme, which aims to build a fusion power plant in the UK by 2040. No other country has committed to a fusion power plant concept with a deployment date.** Notwithstanding the technical risks, the STEP programme provides a means to drive technical progress and scale up industrial capability in fusion.

Since 2020 the UK has also invested in fusion facilities, infrastructure and skills and provided additional support for private-sector led fusion innovation. These new opportunities to reduce technical risk and house commercial fusion activity is building investor confidence in the UK supply chain around fusion. In 2023 the UK launched the Fusion Futures programme, as an alternative means to Euratom association to support the UK fusion industry in building capability and capacity during the 2020s, accelerating the commercialisation of fusion and de-risking the construction phase of STEP. These interventions constitute a fusion programme globally unrivalled in scope, scale and

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[22] The Joint European Torus (JET) has been the focal point of the European fusion research programme for the last 40 years, https://ccfe.ukaea.uk/research/joint-european-torus/
[23] https://www.gov.uk/government/news/fusion-energy-record-demonstrates-powerplant-future
[24] The DEMOnstration power plant, (DEMO), is being developed by EUROfusion as ITER's successor. https://euro-fusion.org/programme/demo/
[25] Mega Amp Spherical Tokamak https://raeng.org.uk/news/major-project-award-for-team-behind-machine-vital-to-developing-commercial-power-from-nuclear-fusion

ambition, albeit with areas identified for collaboration where UK capability can leverage expertise elsewhere.

*February 2025*