Government
Office for Science

FUSION ENERGY

Around the world, scientists and engineers are trying to harness the process that powers the sun and stars for limitless clean energy.

CONTEXT

Technology advances and results from projects in Europe and North America have led to increased optimism that fusion will deliver. There is an increasing focus on delivering real-world systems that can demonstrate net energy gain and produce electricity, for example the UK STEP programme.

FUTURE THINKING

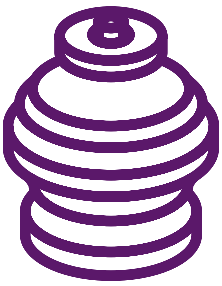
Several private companies have set the 2030s for delivery of pilot power plants but there's still lots to explore. Some experts consider the 2040s a more likely timeline to reach national electricity grids, with the 2050s and beyond where fusion could contribute significantly to the energy mix. Fusion research is tackling extreme challenges of physics and engineering and creating technologies with use in other sectors.

TECHNOLOGY

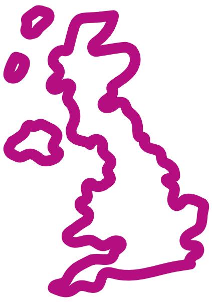
Fusion uses very high temperatures (>100 million °C) and densities to fuse hydrogen atoms together in a reaction that releases energy. This is captured as heat and used to create electricity. There are multiple approaches that use strong magnetic fields, compression, or a combination to create the extreme conditions required.

UK POSITION

The UK has a globally recognised strength in fusion R&D, with various academic groups and a growing cluster of world-leading capabilities and companies around UKAEA*. The UK produces high quality research, and moved quickly to clarify future regulatory intent, but faces challenges in growing skills, infrastructure, and supply chains for a future fusion industry.



60% of fusion companies founded since 2017.



2ND globally for research quality.

Source: Dimensions

$4.7 BILLION private investment in fusion globally.

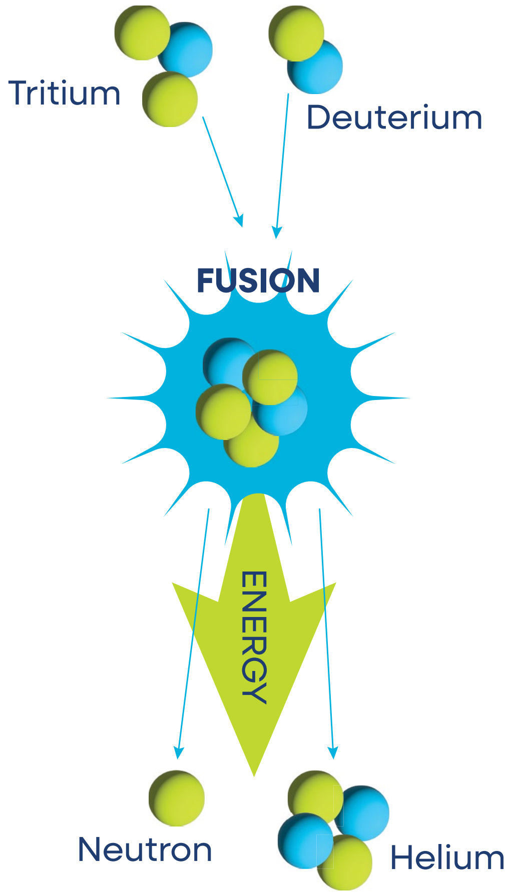
* UK Atomic Energy Authority

APPROACHES TO FUSION ENERGY

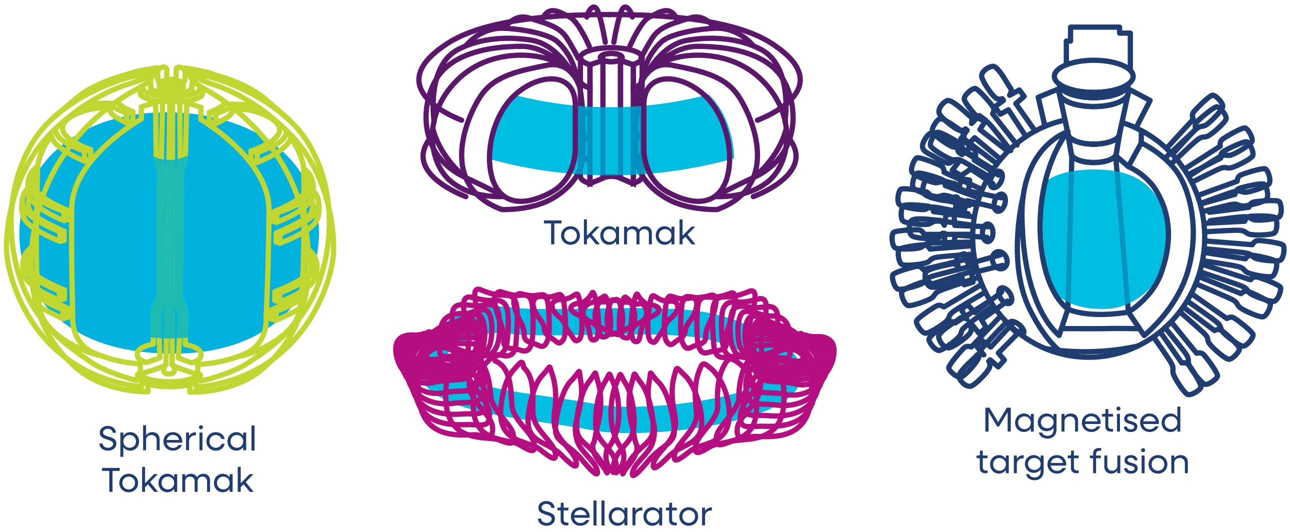
Fusion reactors are expected to combine two types of hydrogen, mainly deuterium and tritium, to produce helium and a neutron. This neutron carries a large amount of energy which can be captured as heat by the reactor and used to generate electricity. A key milestone that no fusion approach has achieved is net energy gain – where the energy produced by the system is larger than the total amount required to run it.*

- **Magnetic confinement** uses high strength magnetic fields to confine a plasma, along with external heating methods to reach the required temperature for fusion to occur.
- **Inertial confinement** uses repeated compression of fuel pellets that create short-lived but extremely hot and dense plasmas (~100x the density of lead) confined by their own inertia.
- **Magneto-inertial confinement** uses magnetic fields to confine a "low" temperature dense plasma before using the compressional heating of inertial confinement.

These categories broadly describe the main approaches to fusion being pursued. Within each approach are more specific methods which will vary further between developers (e.g., Laser or shock-driven inertial confinement).



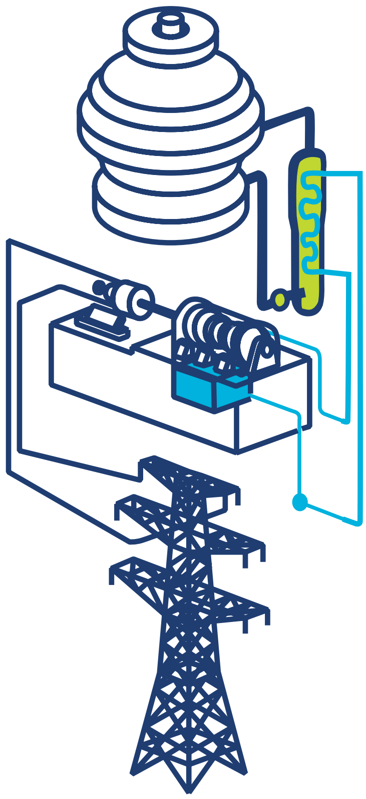
TYPES OF FUSION REACTORS



*Whilst the National Ignition Facility (USA) has achieved net energy gain considering the energy delivered to the target vs released by the reaction, much more energy was required to initially power the 192 lasers used.

TECHNOLOGY CHALLENGES

Materials: Fusion power plants will host some of the most extreme conditions imaginable. The materials and components used will need to withstand high temperatures, changes in temperature, bombardment with neutrons, and more. Developing suitable materials that can perform under these conditions, and be easily maintained, is a key challenge.



Fuel: Global tritium supplies are limited, and so fusion power plants are expected to "breed" their own to be self-sufficient. Moving beyond experimental results into demonstrable systems that can create and recover tritium for use is an ongoing challenge.

Systems Integration: A fusion power plant will need a huge array of complex systems to function. Even where the technology is readily available (e.g. steam turbines), bringing together these systems in an efficient way that enables operation and remote maintenance is a complex challenge.

OPPORTUNITIES

- **UK leadership:** The UK has a cluster of world-leading capabilities and companies around UKAEA. Experts were enthusiastic that the UK could build on this to accelerate development of commercial fusion in the UK.
- **Sustainable Energy:** If successful, fusion could enhance global energy sustainability and meet rising electricity demand. In the UK, it could improve energy security and reduce reliance on foreign energy.
- **Future Value Chain:** Fusion represents a potentially high value future market. Building broad capability in relevant areas such as advanced manufacturing and robotics could position the UK for future opportunities.

CHALLENGES

- **Technology Development:** There are significant technical hurdles before fusion becomes commercially viable. These include high-performance materials, fuel cycle and remote maintenance technology, and integration of complex systems needed for a fusion power plant.
- **Supply Chain & Skills:** Meeting future demand for fusion energy, if realised, will need supply chains and skills to scale rapidly from where they are today.
- **Clean Energy Transition:** The transition to clean energy may create challenges and compound geopolitical tensions. This is also possible with the roll-out of fusion energy, depending on its speed, distribution, and the supply chain. Adoption of fusion will likely depend on the continued drive for clean energy and cost competitiveness.

Please share your views.
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