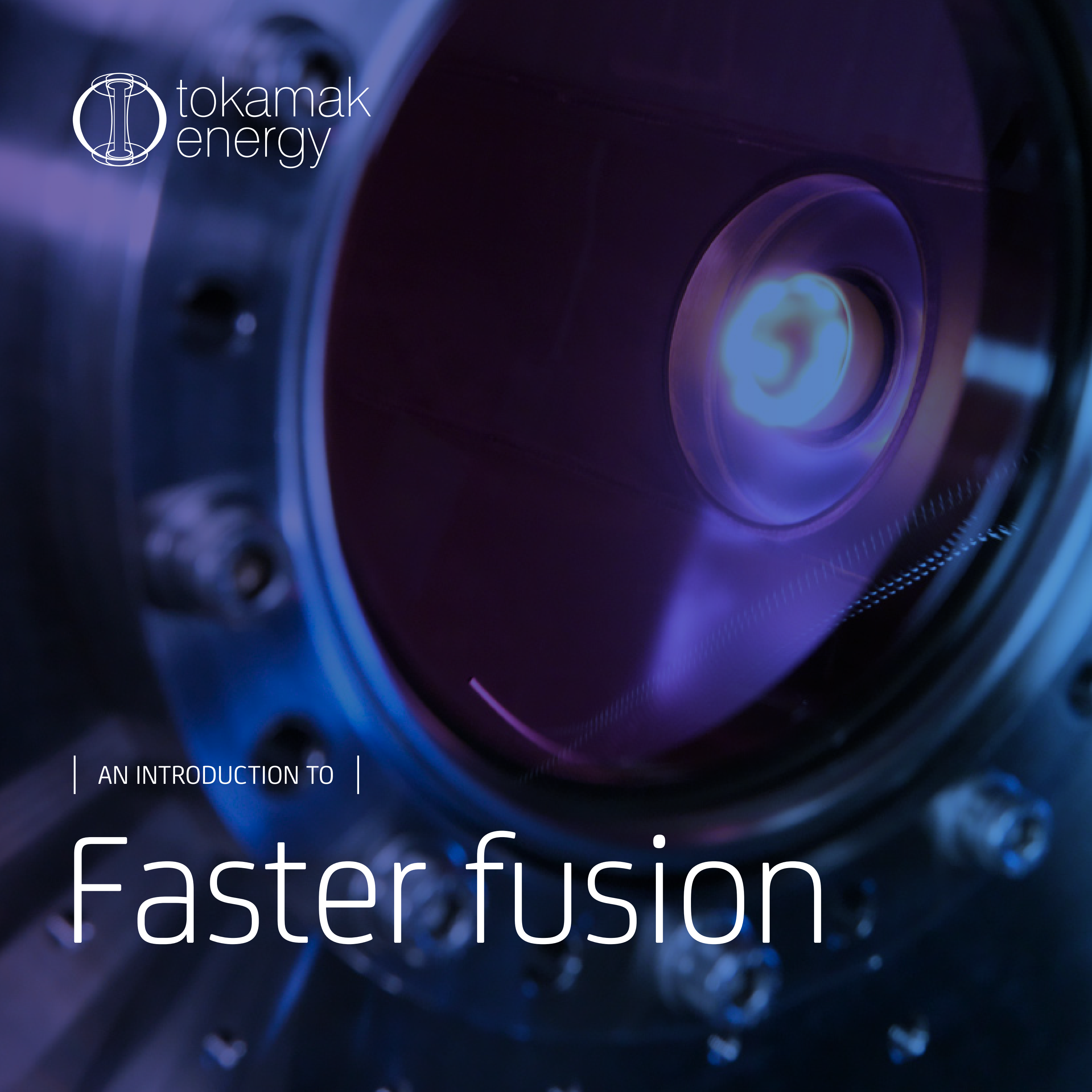


tokamak energy

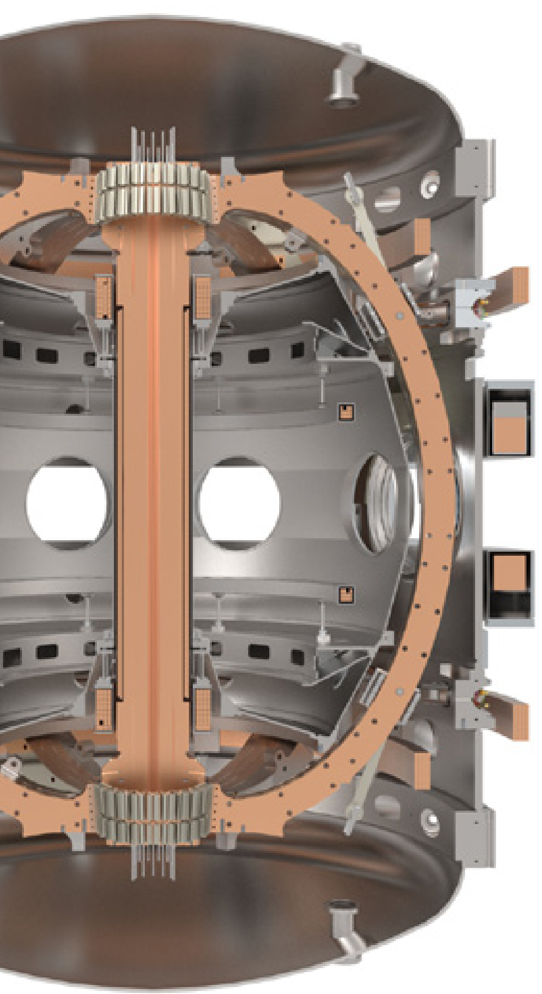
AN INTRODUCTION TO

Faster fusion

What is fusion?

Fusion is the energy of the stars. Small atomic nuclei join together to make larger ones, which releases energy. All the heavier elements in the universe were made this way.

Fusion only happens at very high temperatures because it is forcing together particles that would usually be far apart. Nuclei are all positively charged particles, so they keep away from each other just like magnets of the same polarity repel. Nuclei don't want to come together, so the only way for fusion to occur is to heat things up a lot, like in the stars.



Why do we care?

The world needs a base-load power source that is abundant, safe and CO2-free. Fusion is one of the few options we have.

How could we make the energy of the stars on Earth?

First it involves heating our fuel to hotter than the centre of the Sun – over a hundred million degrees. At these temperatures, the electrons of atoms break away from their nuclei to create a soup of very fast-moving, electrically-charged particles called plasma. Somehow we have to confine this, or trap it, so that we can keep the fuel hot enough for long enough for fusion to occur. Different methods have been proposed and the main contenders are: inertial (or laser) fusion, which uses lasers to heat and confine the fuel; or magnetic fusion, which uses magnetic fields.

Within the field of magnetic fusion, the tokamak machine is the most developed and best understood.

What is a tokamak?

The word "tokamak" is a Russian acronym that stands for "toroidal chamber magnetic coils".

That is, the tokamak is a toroidal – or ring-doughnut-shaped – vessel with magnetic coils that make a trap for the plasma. The plasma is heated using microwaves or powerful particle injectors and it has to be stabilised by carefully controlling the shape of the magnetic fields.

When will we be using fusion power?

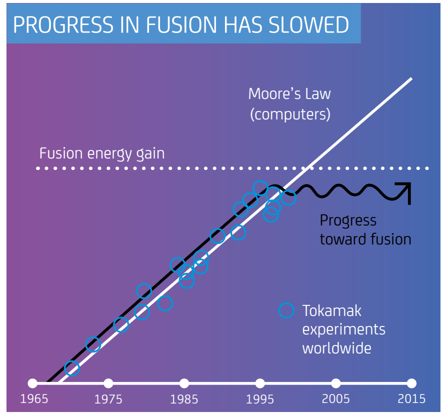
That is the hardest question to answer. Research started in the 1950s and the big joke is that fusion is 30 years away… and always will be. We don't think that's true. We think faster fusion is possible, but it is harder than was originally thought. Globally, tens of thousands of people are working on it – and making progress – but it takes time, money, new materials and technology, and intelligent new minds coming into the field to solve the puzzle of how to create fusion power on Earth.

When developing new technologies and expertise, timescales are difficult to predict. But Tokamak Energy aims to demonstrate industrial scale heat from fusion by 2025 and commercially viable fusion power by 2030.

Why has it taken so long?

Did you know that scientists have actually achieved fusion? Unfortunately, so far they have put more energy in to do it than they got out. The JET tokamak in the UK holds the world record for fusion power. In 1997 JET made 16MW – about 65% of what was put in to heat the plasma

Progress towards fusion power was rapid for 30 years – slightly faster than Moore's law for computers. But has slowed since the JET achievement in 1997. Why?



The answer lies in the physics. The fusion power we get out depends on the efficiency of the machine, the strength of the magnetic field and the size (volume) of the toroidal vessel:

$$P \propto \beta^2 \times B_T^4 \times V$$

Back in 1985, when engineers were designing the next tokamak after JET, the efficiency of the machines and the magnetic field strength were limited by the technology of the time. Increasing size seemed the only way forward. The world agreed to construct the giant ITER tokamak in France. Feats of engineering such as this take time. Construction is now well underway but ITER won't be operating for several years yet – probably mid-to-late 2020s.

Also, plasma physics is very complicated. Keeping hot plasma trapped requires a good understanding of how it behaves. With all the research over the past decades, physicists are now in a better position to improve the performance of fusion plasmas.

Can we achieve fusion faster?

We believe so. In the last few decades new technologies have emerged. Building on all the work that has gone into JET and ITER, it now seems feasible that by using a slightly differently shaped (spherical) tokamak combined with the latest generation of high temperature superconductors for magnets, we could make smaller, cheaper machines and so make progress faster.

What is a spherical tokamak?

A spherical tokamak is one that is squashed up so it looks more like a cored apple than a ring doughnut. It therefore makes more efficient use of the high magnetic field at the centre.

What is a High Temperature Superconductor?

A superconductor is a material with zero electrical resistance when it is extremely cold, so it doesn't heat up when current flows through. Conventional superconductors are cooled by liquid helium to -269C (or 4K). High Temperature Superconductors (HTS) become superconducting at a higher temperature, around the boiling point of liquid nitrogen at -196C (77K). That's still rather cold, but it represents a big saving in cooling energy.

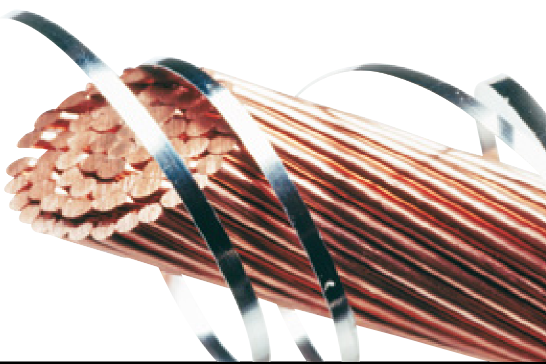
How can these help fusion?

Spherical tokamaks can generate higher plasma pressure for a given magnetic field. In other words, they have a higher efficiency than conventional tokamaks. High temperature superconductors can give higher magnetic field and better performance than conventional ones. Combined, it is possible to achieve fusion power without increasing the machine size so much.

Additionally, high temperature superconductors can support a much higher current density than conventional superconductors (meaning they can achieve higher magnetic fields for the same thickness of superconductor), so they will work with the squashed-up shape of the spherical tokamak. HTS magnets will be a game-changer for fusion, but scaling up requires new systems and techniques.

Our recent work (Costley et al, Nuclear Fusion, 2015/2016) shows that smaller, cheaper tokamak fusion reactors are possible. In principle we could attain similar fusion performance to an ITER-scale device at only about 1/20th the volume. We are working on determining the optimum size and design for a future fusion reactor.

We advocate a modular approach to fusion. It may not be necessary to generate the highest absolute fusion power. What is important is the fusion gain (ratio of power out to power in), or rather how much extra energy we can get out. Using several low-power machines with high gain may be better than using one big, high-power machine, and it also gives more flexibility to the power station operator.



What is Tokamak Energy doing to solve the problem?

Tokamak Energy Ltd is a private company based at Milton Park, Oxfordshire, and funded by investors. In collaboration with leading industrial and academic partners, our team of world-class fusion scientists and magnet engineers aims to achieve commercial fusion by breaking the challenge down into engineering milestones:

ST25 Small experimental tokamak with conventional copper magnets. It was used to develop capabilities crucial for reactor operation and can be operated remotely.

ST25 (HTS) The world's first tokamak with high temperature superconducting (HTS) magnets. It pioneered this new technology and held a plasma for 29 hours in 2015.

ST40 The world's first high-field spherical tokamak (>2 Tesla). It has copper magnets and will verify theoretical predictions as well as reaching plasma temperatures of 100 million degrees.

HTS Magnet Demonstrator - This will be a full-scale high temperature superconducting magnet designed for high-field tokamak operation.

ST-F1 An HTS tokamak combining knowledge gained from previous milestones to generate industrial scale fusion power and demonstrate net energy gain. Another world first for us!

ST-E1 This will be the first fusion power plant module. It will produce over 150MW and could be used alone or as part of a "farm" of modular devices.

For the future we see a modular series of such 100-200 MW power plants. These could be manufactured to a standard design and shipped around the world.

Are we nearly there yet?

We are getting closer. It is now acknowledged that the spherical tokamak design with HTS magnets offers the smallest, most cost-effective solution. This is our solution. Yet there are many complex engineering challenges that need to be overcome for demonstration and commercialisation of fusion. Our unique approach is centred on rapid innovation using the latest materials and technology, but building on decades of scientific research and experience.

Once fusion electricity is achieved, our scalable technology could be rolled out across the world as a solution to one of humanity's greatest challenges: clean and sustainable energy for all, for thousands of years into the future.

This strategy gives us – and the world – a faster way to fusion.

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