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Tokamak power

Making progress with nuclear fusion

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Energy is a necessity for life. Without it we wouldn't have food, warmth, clean clothes, light and all the electrical appliances we use in our everyday lives. Our major sources of energy are fossil fuels – oil, coal and natural gas. As the world population rises and demand for electricity increases, these energy sources are diminishing. If we continue to use fossil fuels at an increasing rate they will soon run out. Then what will we do to provide us all with electricity, heating, transport....?

We mustn't run out of energy, but we mustn't pollute either. We have to find alternative, cleaner ways to provide our energy. These include nuclear power and renewable energy sources, such as geothermal, hydroelectric, tidal, wind and solar. Although these energy sources are naturally replenished, they can take up a lot of space in order to provide enough power. For instance, large spans of land in the UK are wind farms, which provide only a small percentage of the UK's power. In addition to this, nature can be unpredictable. There will be peaks and troughs in energy generation due to varying wind speeds, thus making this energy source unreliable in times of demand. We need a better solution. Fusion energy could be the answer.

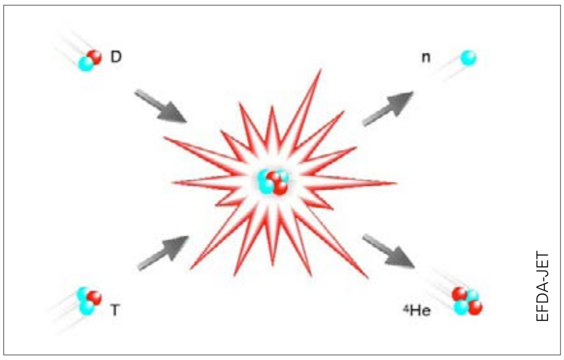

Figure 1 *The fusion reaction: where deuterium (D) and tritium (T), isotopes of hydrogen, fuse to make helium (He). A neutron and some energy are by-products of this reaction.*

What is fusion?

Fusion is the process that powers the stars, including our very own Sun. Within the core of a star, small atomic nuclei are joined together to make larger nuclei (**Figure 1**). Heavier elements such as helium are made in this process. This is where the saying 'we are all stardust' comes from. All the elements you see in our Universe came from the stars: the element factories.

The Sun produces a lot of energy. Remember those times where you have been out on a sunny day and felt a burning sensation on your skin because of the Sun. This is from 150 million km away! Now just imagine if you were stood next to it! If only we could harness this process on Earth and use it to generate power.

Scientists are coming up with innovative ways of achieving fusion on Earth. The world requires a power source that is abundant, safe and carbon dioxide-free; and fusion offers this. But how can we harness the power of the stars? Scientists have been trying for decades. Now businesses are getting involved. Tokamak Energy, a private company based at Milton Park in Oxfordshire UK, aims to accelerate the development of fusion energy using new technologies and smaller machines.

Fusion can only happen at extremely high temperatures, approximately a few hundred million degrees. Nuclei are positively charged and when they come close together they repel each other, because like charges repel. Therefore, trying to get nuclei close together is a huge challenge. Having high temperatures (and pressures) causes the nuclei to gain a large amount of kinetic energy so that they can overcome this repulsion and fuse.

At such high temperatures, atoms no longer exist. Instead the electrons break away from the nuclei forming a plasma. Plasma is the fourth state of matter and can be thought of as a soup of very fast-moving charged particles (ions and electrons). In this environment fusion can occur (**Figure 2**), but we must somehow be able to hold this very hot plasma in a container. To do this, we can either use magnetic cages (magnetic fusion) or lasers to heat and confine the fuel (laser or inertial fusion). Tokamak Energy's research is in the field of magnetic fusion, and they use machines known as tokamaks.

What is a tokamak?

Tokamak is a Russian acronym for 'toroidal chamber – magnetic coils'. That is, a tokamak is a doughnut-shaped (toroidal) vessel surrounded by rings of magnets. The charged particles within the plasma are influenced by magnetic fields, so the tokamak acts as a magnetic cage trapping the plasma. By varying the shape of the magnetic fields we can stabilise the plasma to make sure it doesn't hit the walls. (This is not dangerous, since if we lose control the plasma simply cools, but we do not want to slowly melt our apparatus, atomic layer by atomic layer). The plasma is heated using microwaves or powerful particle injectors – a bit like steam heating up the milk in a cappuccino.

Tokamak Energy combines two emerging technologies in their fusion experiments: spherical tokamaks and high temperature superconductors. A spherical tokamak is a squashed tokamak that resembles a cored apple rather than a doughnut (**Figures 3**).

Containing super-hot plasma is just one challenge of fusion power. A second is to extract energy so that electricity can be generated.

Figure 2 A tokamak with new, high temperature superconducting magnets used by Tokamak Energy. Plasma can be seen in the chamber.

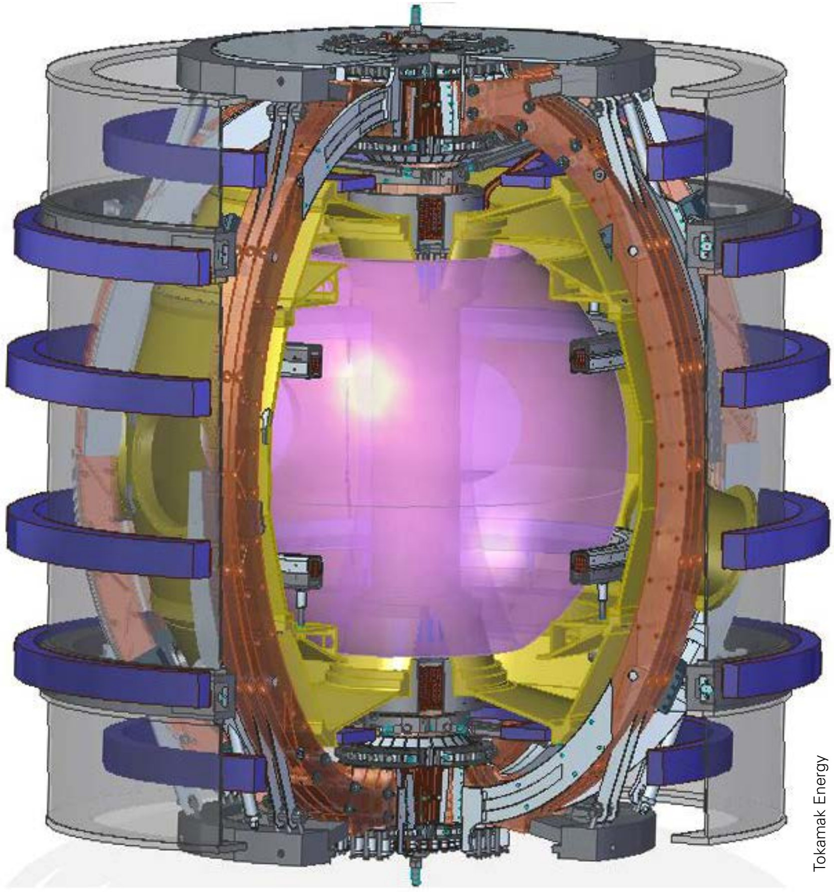

Figure 3 Inner workings of a spherical tokamak. The plasma would sit in the purple region and the magnets are shown in copper and blue.

What are high temperature superconductors?

A superconductor is material that has zero electrical resistance when a current is passed through it. Normally this special characteristic is only seen when the material is extremely cold. Conventional superconductors are cooled down to -269°C with liquid helium. A high temperature superconductor, on the other hand, can exhibit this property at a higher temperature of -196°C, about the boiling point of liquid nitrogen. Because of this lower temperature there is a large saving in the energy and costs required to cool the superconductors (**Figure 4**).

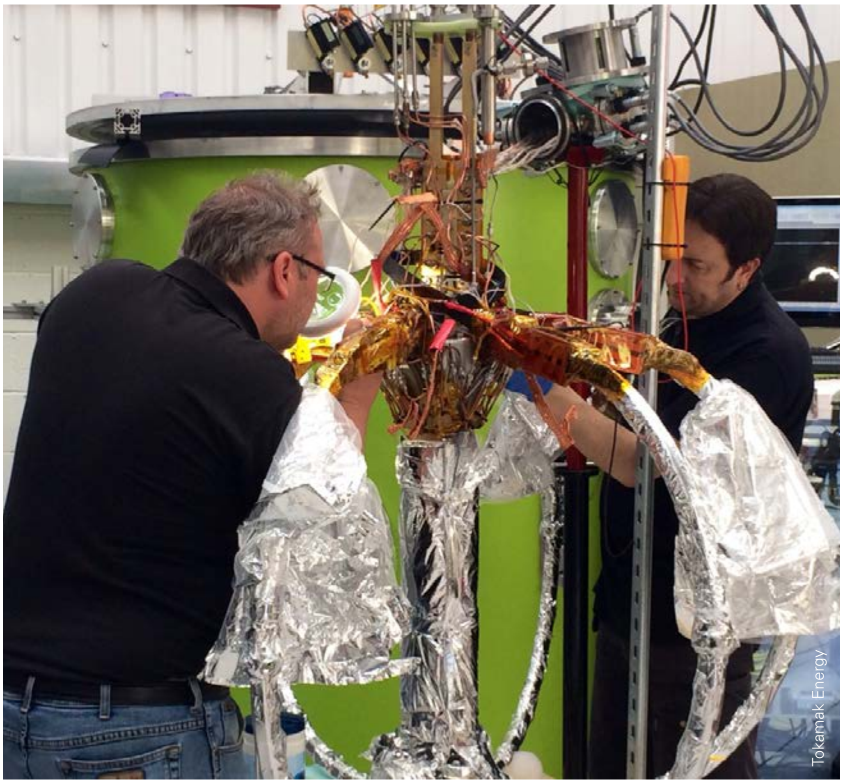

Figure 4 *Assembling the high temperature superconducting magnets.*

A spherical shape and high temperature superconductors – how do these help fusion? Spherical tokamaks offer higher efficiency than conventional tokamaks as they naturally provide a higher plasma pressure for a given magnetic field. This means that the magnetic trap is better than in a regular tokamak. High temperature superconductors generate higher magnetic fields than conventional superconductors, and higher magnetic field equals a better trap.

An added advantage to using high temperature superconductors is that they can be made into narrow tapes that can be wound into magnets that take up considerably less space than magnets made from ordinary superconductors or copper. This works well with the squished design of a spherical tokamak and means we can make smaller machines.

Using these new technologies, Tokamak Energy can build smaller, cheaper machines and therefore make progress faster.

When will we be using fusion power?

If you ask a scientist this question they would probably laugh first and remind you of the big joke, that fusion is 30 years away and always will be. Research into fusion began in the 1950s. Since then we've gained a lot of knowledge about plasmas and fusion, but have yet to get more energy out of our machines than we put in. The current world record for fusion power was achieved by JET (Joint European Torus), the world's largest and most powerful tokamak, based at Culham. In 1997, JET got out 65% of the energy it put in. Tokamak Energy aims to demonstrate fusion energy gain (more energy out of the system than put in) in a compact tokamak in five years, and the first electricity from fusion in ten years (**Figure 5**). In your lifetime, you may be able to see the world powered by tokamaks!

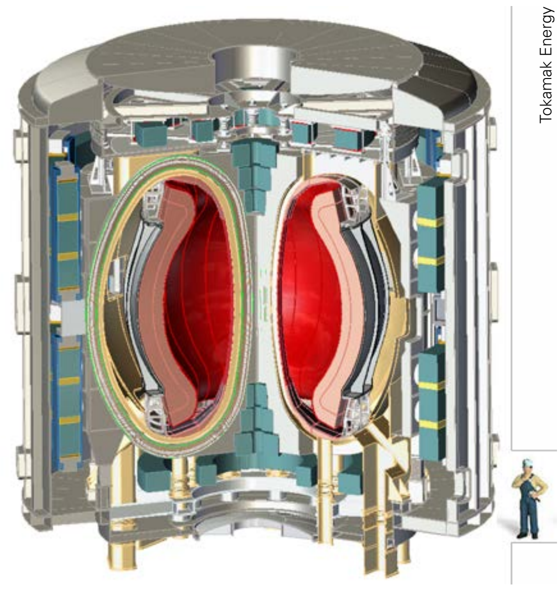

Figure 5 *Tokamak Energy's concept for the first fusion power module.*

However, we must remind ourselves that science can be unpredictable and that we may encounter new challenges in the future, so it is hard to say for certain when we might be using fusion power. The future will hold opportunities to learn new things and – who knows – you could be the next scientist to help turn this dream into a reality.

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Look here!

Tokamak Energy hold the world record for holding a plasma in one of their machines for 29 hours! (The previous record was only 5 hours.): *www.tokamakenergy.co.uk*

Twitter: *@TokamakEnergy #fasterfusion*

YouTube: *bit.ly/1QadDVz*