Accelerating fusion

The promise of electricity generated from nuclear fusion is one that has always seemed too far in the future to be taken seriously. Tokamak Energy, however, believes the combination of two emerging technologies that together enable the construction of smaller, cheaper machines open up the way to commercialisation. Dr Melanie Windridge explains.

The ST25 with high temperature superconductors. High temperature superconducting magnets could be used to create high magnetic fields in a compact spherical tokamak

The world needs widely available energy that is reliable, affordable and does not produce carbon. The only way to accomplish that goal is by developing new tools to power the world," begins the new Breakthrough Energy Coalition on its website. Recently set up by Bill Gates and more than 20 other visionary billionaires, the Coalition is a global group of private investors aiming to accelerate progress on clean energy.

Tokamak Energy is working on nuclear fusion, the long-awaited holy grail of the energy field. The reaction that powers the sun and the stars, fusion is terrifically hard to do. But harness this stellar reaction and clean, green, safe and abundant energy could be a reality around the world. The promise is tantalising.

However, it has been a long road. Decades of research by scientists in government-funded labs and universities led to the first earthly fusion reactions in the late 1990s, with a world record output achieved of around 65 per cent of the input energy.

Good work is still being done, progress is still being made, but it is well known that government-funded research can be slow, and taking an immature technology from concept to commercialisation is notoriously tricky. The Breakthrough Energy Coalition plans to "support companies that are taking innovative clean energy ideas out of the lab and into the marketplace." Not just for fusion, of course but for any potentially world-changing energy solutions that need that step up.

Nuclear fusion is the joining together of two small atomic nuclei to make a larger one. The easiest reaction to achieve on Earth is between two types of hydrogen – deuterium and tritium. Collide these two isotopes together at high speed and they create helium (the safe, party-balloon gas) and a fast neutron. The high speeds are required to overcome the repulsive force between the two positively charged nuclei. It ensures that fusion reactions only occur under very high temperatures – hundreds of millions of degrees – when the fuel is in a 'plasma' state of freely moving electrons and nuclei.

This high-temperature, fluid plasma needs to be held trapped and steady. The world-leading concept is the 'tokamak', a ring-doughnut-shaped device that uses a complex pattern of magnetic fields, generated by large electromagnetic coils, to isolate the plasma away from the walls of an evacuated inner chamber. This isolation is important not because plasma-wall contact is dangerous or explosive, but because touching the wall would cool the plasma so much as to extinguish any fusion reactions.

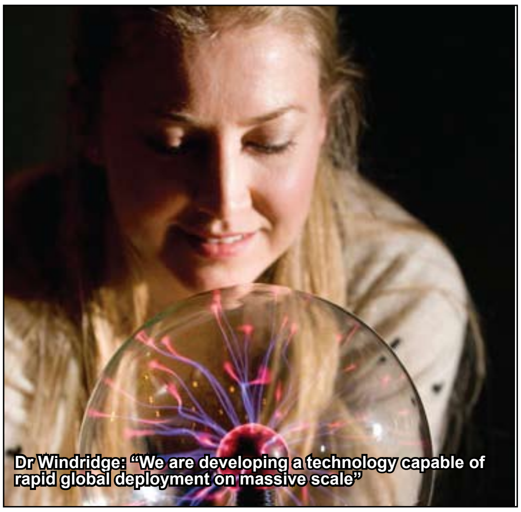
Tokamaks are the most researched of any fusion device and have a good history of progress, the apex of which was the world record generation of 16 MW of fusion power by the Joint European Torus (JET) in 1997. JET has since been upgraded and continues to do cutting-edge research. At the same time a larger tokamak, ITER, is being built in France.

When it begins operation it aims to get ten times as much energy out as is put in, thereby proving the feasibility of fusion energy. But various delays mean that ITER now will not start operating until the late 2020s, and various companies in the US and Britain have sprung up with the express aim of achieving fusion faster. For the sake of our energy security, developing countries and the planet, we cannot afford to wait that long.

Tokamak Energy's difference in the fusion energy field is the combination of two emerging technologies that together enable the construction of smaller, cheaper machines and open up the way to commercialisation.

If we track back to the 1980s, two unrelated things emerged that would later have the potential to change the fusion game. One was the discovery of high temperature superconductors, a huge unexpected breakthrough that promised to revolutionise industries like electricity transmission and energy storage. The other was the concept of 'spherical' tokamaks, squashed-up versions of the conventional donut tokamaks such as JET. The spherical design showed dramatically improved performance.

Moving forward to 2010, Tokamak Energy was set up as a spin-out from Culham Laboratory in Oxfordshire (originally called Tokamak Solutions) to commercialise compact tokamaks for research applications. Then, in 2011, high temperature superconductors became available as engineering materials some 25 years after they were first discovered. Suddenly there were new possibilities.



Dr Windridge: "We are developing a technology capable of rapid global deployment on massive scale"

The high temperature super-conducting magnets could be used to create high magnetic fields in a compact spherical tokamak. So instead of building ever-larger tokamaks, with huge costs and long timescales, one could increase the magnetic field in smaller machines. We are building up increasing evidence that this really could work.

The Tokamak Energy approach is to break down the problem into a series of engineering challenges and raise funding for successive steps. The first of these was to build a tokamak with all magnets made from high temperature superconductors, which was achieved in 2015.

The next is our Hundred Million Degree Challenge – reaching these fusion temperatures in a compact tokamak in the next few years. Alongside the R&D, we are using the thrill of the physics and engineering challenge of such an emotive subject to engage the public, particularly school students, in the excitement of fusion energy and science careers.

After achieving 100 million degrees, Tokamak Energy will shoot for energy breakeven, then we will go sufficiently beyond breakeven to produce electricity for the first time. From there we will go on to build reliable, economic, fusion power plants – a challenge in itself when one considers the engineering realities of creating such a hostile environment in the centre of a device with a desired operation lifetime of several decades. These are the plans, but they need money and good people to make them happen.

We at Tokamak Energy have a strong feeling that the time is right for the accelerated development of fusion energy. This is partly because of the maturity of the key technologies, but partly due to the desperate need for clean, green energy. At last, judging by the Breakthrough Energy Coalition and Mission Innovation initiative, there appears to be political and private enthusiasm to take bold steps to tackle the problem.

The UK government announced in the Autumn Statement that it will invest at least £250 million over the next five years in an ambitious nuclear research and development programme. The vast majority of the investment will of course go to support the new generation of fission reactors, but some could help the progress of fusion energy, either directly or through solving materials and engineering challenges common to fusion and fission, such as robotics for remote handling.

The Paris Climate Change talks reached a surprising political consensus, not just that something should be done, but that carbon emissions should be zero by the second half of the century, or even sooner if the 1.5°C temperature rise goal is to be met. The question of how to do this has not been addressed, but we know from examples like the Apollo missions that big goals can be tackled remarkably quickly if political will is matched by investment. This is where the Breakthrough Energy Coalition could be so valuable, by providing "truly patient flexible risk capital" to companies in that difficult stage between concept and product.

Climate Change and Green Energy have also been major topics at the World Economic Forum Annual Meeting in Davos. Tokamak Energy is proud to have been selected as a Technology Pioneer of the World Economic Forum 2015 – a selection made on the basis of having a large potential global impact in the sphere of Decarbonising Energy. We are developing a technology capable of rapid global deployment on massive scale, as will certainly be necessary to meet the commitments made at the Paris talks.

Technology Pioneer status comes with an invitation to attend the Davos meeting. One of the sessions where Tokamak Energy was speaking was entitled *"Will science save us?"* The answer, we believe, is yes – at least as far as clean energy is concerned – but only so long as the science is well linked to engineers and entrepreneurs.

We need to tackle the challenge of fusion energy together. The scientific conceptual work underpinning ITER has shown that fusion power from tokamaks is technically feasible. Engineers and entrepreneurs need to take that scientific basis and make it happen. We intend that Tokamak Energy will be part of this solution.