NUCLEAR FUSION: THE PERFECT ENERGY SOLUTION, IF ONLY IT WASN'T SO DIFFICULT TO ENGINEER

It may still be at the experimental stage but scientists are confident that the challenges of nuclear fusion are known and can be overcome. If they are correct, the future of energy production will look very different indeed.

By Mike Scott

Nuclear fusion is the Holy Grail of clean energy. Clean, safe and with hugely plentiful raw materials, it involves no carbon emissions and for proof that it works you need only look up – fusion is the process that makes the sun and the stars shine.

"Fusion is the perfect energy source except for one thing," says Professor Steve Cowley, head of the UK's Culham Centre for Fusion Energy. "It is really hard to do."

However, within the industry there is a real sense that the significant challenges of creating fusion can be overcome, even if there is disagreement about exactly how to do this.

While fission – today's nuclear power – involves splitting atoms of heavy elements to produce energy, fusion involves bringing together atoms of two different types of hydrogen known as deuterium and tritium. Deuterium is common and can be extracted from seawater. Tritium is very rare but can be created in fusion reactors. Fusing these together creates helium but it also releases a huge amount of energy. Fusion is incredibly difficult because the particles do not naturally want to fuse together and capturing the energy is problematic because the energy, although vast, fades almost instantly.

Only a few grams of each material are needed to generate fusion. While a 1GW coal-fired power plant requires 2.7m tons of coal per year, a fusion plant of the same capacity would only require 250kg of fuel per year, half of it deuterium, half of it tritium.

The sun's fusion reactions are generated thanks to an enormous gravity field. On earth, in the absence of such a gravity field, temperatures of 150m-200m degrees Celsius are required, although once the process is running it is self-sustaining, says Cowley.

Two key approaches are being explored to create and contain such high temperatures, with the US government championing laser fusion and an EU-led consortium that also includes China, India, Japan, South Korea, Russia and the US focusing on using magnetic fields to contain the extremely high temperatures generated by the reaction.

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The Americans are focusing on laser fusion at the National Ignition Facility, which was opened in 2009 at the Lawrence Livermore National Laboratory. "We are using a laser to compress the fuel to an extremely high density and high temperature to mimic the conditions of the sun," says Mike Dunne, programme director for fusion energy systems at NIF.

Ball bearing-sized pellets of deuterium–tritium are injected into the centre of a large, empty chamber and then hit by beams from the world's most powerful laser to compress the fuel to about 100 times the density of lead, for a few millionths of a millionth of a second. The energy from this reaction emerges as neutrons, which react with a lithium layer in the wall of the chamber to produce heat, explains John Parris, of the UK-based HiPER (European High Power Laser Energy Research) project.

Given the temperatures created, it is unsurprising that large amounts of energy are needed to kickstart fusion. The breakthrough that will bring fusion large amounts of commercial funding is when scientists demonstrate net energy gain – when more energy comes out of the reaction than goes in. "It will be one to two years until we get far more energy out than is delivered," asserts Dunne confidently.

The consortium behind ITER, the International Thermonuclear Experimental Reactor, which will be based in South-West France, is taking a different approach. The fuel is heated and compressed using superconducting magnets. The plasma that is created is contained within a magnetic field contained within a giant doughnut-shaped chamber known as a tokomak. The ITER team hope to create a fusion reaction that releases around 10 times more power than is used to heat up the plasma to fusion temperatures.

Work started on the ITER site in 2010 but it is not due to start producing energy until 2019. Its funding has been hit by political wrangling in Brussels where the European Parliament recently refused to approve an extra EUR 1.4bn ($1.9bn) contribution to the project, which has seen its budget triple from its original EUR 5bn ($6.7bn) estimate. ITER has been scaled down from its original ambitions as costs have grown, but it seems likely that the project has advanced too far to be cancelled, not least because it is backed by a binding treaty.

Both NIF and ITER are focusing on the front end of the process, the creation of a steady fusion reaction and demonstrating net energy gain, because

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once the heat has been harnessed, it will be simple to add on a steam turbine to generate power.

Fusion research is dominated by NIF and ITER, whose scale and cost "mean that governments see the value of co-operation in order to face a challenge which confronts us all... namely clean, safe, reliable energy for the long term," says Parris.

Because the laser used by NIF has emerged from weapons research, it is designed to fire only infrequently. "Once we know it works, we will focus on moving from one bang to 10 bangs per second," Parris says. This is what HiPER is focusing on. Mike Dunne, the former head of HiPER, is working on similar research at NIF's Laser Inertial Fusion Energy (LIFE) programme, "which will take the proof-of-concept and convert it into a power plant".

"Basic physics tells us that these things [fusion reactors] want to be very big and very hot," he adds, and this mitigates against smaller scale private sector fusion projects. Nonetheless, a number of companies are pursuing their own lines of research.

Vancouver-based General Fusion raised $13.8m in Series A funding for its "magnetised target fusion" approach in 2009, with backers including Chrysalix Energy Venture Capital, GrowthWorks, Braemar Energy Ventures and Entrepreneurs Fund. SET Venture Partners put in an additional $1m in 2010.

"Magnetic fusion is all confinement and no compression, while laser fusion is no confinement but extremely high-density," says Michael Delage, vice-president of business development at General Fusion. He describes his company's "magnetised target fusion" as somewhere in between – plasma is confined in a magnetic field and then compressed.

NIF and ITER involve huge technological challenges – operating massive superconducting magnets at 4 degrees Kelvin for ITER and creating and operating the world's largest laser for NIF – and are therefore incredibly expensive, Delage says. "In our intermediate approach, we are able to form magnetised plasma and compress it using much less expensive techniques," he says. "We can do this on a budget of tens of millions of dollars rather than billions."

Excavation of the giant tokamak (the doughnut-shaped chamber) in South-West France by the consortium behind ITER, the International Thermonuclear Experimental Reactor, which hopes to start producing energy by 2019.

Source: Engage Consortium.

General Fusion is in the middle of a four-year project to demonstrate its reactor concept at full scale. The first phase is to build and demonstrate key components at full scale. Its aim is to create devices capable of producing about 100MW of electricity, although the company says that there is no reason why it cannot be scaled up to the gigawatt level that the large-scale projects are likely to aim for.

Another approach taken by a number of companies uses a mix of hydrogen and boron as a fuel and seeks to create electricity directly from the charged particles that the fusion creates.

The secretive, California-based Tri-Alpha Energy raised $40m in series C funding in 2007 from backers that reportedly included Goldman Sachs, Venrock, Vulcan Capital, Enel Produzione and PIZ Signal, and it was reported last year that it had raised a further $50m.

EMC2 Fusion, another California group that is part-funded by the US Navy is also doing research involving hydrogen and boron, as is New Jersey-based Lawrenceville Plasma Physics, which is more public about its work.

Bypassing the production of heat to drive a steam turbine will cut costs and make the process safer because there is no radioactive waste at all, says Eric Lerner, president and lead scientist at LPP. This approach also means that the technology becomes viable at a smaller net energy gain.

The private sector approaches are necessarily smaller scale than NIF or ITER but this makes them more flexible and able to be sited near sources of demand, he claims. LPP believes its device will operate effectively at about 5MW, although it would be easy to scale up with a modular approach.

LPP recently announced it had demonstrated the confinement of ions with energies in excess of 100 keV (the equivalent of a temperature of more than 1bn degrees Celsius) in a device called a dense plasma focus. Confining energy on this scale allows hydrogen-boron fuel to be burnt to produce fusion energy.

Initially funded by NASA's Jet Propulsion Laboratory, LPP has struggled to raise funds since NASA withdrew from fusion research in 2001. "It took seven years to put together the funding for our current device," says Lerner. "We raised the money from individual accredited investors and the Abell Foundation. We are continuously raising money."

LPP has an ambitious time frame to introduce boron into its machine by the end of 2011. Actual net energy gain is

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not necessary to take the project to the next stage, he says. The company – and any other research project – simply has to show that net energy gain is achievable for the funding floodgates to open.

Lerner says that until someone comes up with a working prototype, governments should be funding alternative approaches to fusion rather than pinning all their hopes on the outcome of work at NIF or ITER. “All the alternative projects could be adequately funded out of a budget of no more than $200m,” he says.

However, NIF’s Dunne warns: “Private approaches to fusion have been dogged by over-optimistic speculation about what is possible for decades.”

Both Lerner and Delage agree that credibility will be a major hurdle for private companies until they make a breakthrough. “Credibility is an issue for us today, but we believe that won’t be an issue if we are able to demonstrate net energy gain using our approach,” Delage says.

Meanwhile, companies involved in today’s nuclear industry are seeking out opportunities to position themselves for a fusion future. The engineering firms Atkins of the UK, France’s Iosis and Assystems and Empresarios of Spain have signed a joint venture to work together on the construction of ITER in the Engage consortium.

“We are at the forefront of something new that will be viable in the long term. This is a promising new business stream for us,” says Atkins director of nuclear Chris Ball. “There is a massive amount of opportunity in this field. This is specialist work and you need a credible track record to be in the market.”

Other benefits may well emerge from fusion research. LPP is looking to market a product called X Scan, which will allow engineers to inspect critical infrastructure using the powerful x-rays generated by the company’s dense plasma focus device.

Meanwhile, Oxford Instruments, which is providing GBP 30m ($47.9m) of superconducting wires to be used in ITER’s superconducting magnets, has been able to open up a new production line to produce wires for use in magnetic resonance imaging machines.

Nuclear fusion remains very much at the experimental stage but those involved are confident the challenges are known and can be overcome. The first organisation to demonstrate that net energy gain is feasible is likely to see governments and power companies beating a path to its door. “When we see net energy gain, it will have a significant impact on investor sentiment,” Dunne says. ■

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